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Volume 13 Number 2 December 2025

CONTENTS

Magdalena Raczyńska, Krzysztof Krukowski, Dorota Sobol, Wiesława Lizińska
MANAGEMENT OF SCIENCE AND TECHNOLOGY PARKS IN POLAND 10

Ana Todorova
MEASURING AND REPORTING THE IMPACT OF SOCIAL ECONOMY ORGANISATIONS ON ACHIEVING THE GLOBAL SUSTAINABLE DEVELOPMENT GOALS 24

Vladimir Bukvič
IMPACT OF STRATEGIC CORPORATE INVESTMENTS ON COMPANIES' PERFORMANCE: A CASE OF SLOVENIA 47

Robin Kunju Mol Raj, Marek Vochozka, Jindřiška Vitvarová
ENTREPRENEURSHIP AND REGIONAL ECONOMIC DYNAMICS: EVIDENCE FROM THE LIBEREC REGION (2002–2024) USING GRANGER CAUSALITY AND VAR MODELS 77

Josef Bureš, Vojtěch Bartoš
TOWARDS SUSTAINABLE DIGITAL TRANSFORMATION IN INDUSTRIAL ENTERPRISES WITH A FOCUS ON THE CZECH REPUBLIC 95

Edmunds Čižo, Vera Komarova, Anita Kokarēviča, Jānis Kudiņš, Sergejs Ignatjevs, Inta Ostrovska
PECULIARITIES OF LOGISTICS AND DIGITAL INTEGRATION BETWEEN KAZAKHSTAN AND THE EU 106

Radovan Bacik, Veronika Loumova, Stefan Gavura, Maria Tomasova, David Misko
EMOTIONS AND THEIR IMPACT ON THE BRAND: A NEUROSCIENTIFIC ANALYSIS OF TRUST AND SOCIAL MEDIA CONTENT SHARING IN GENERATION Z 122

Abdullah M. Aljarodi
INSTITUTIONS AND EMPLOYEE INTRAPRENEURSHIP: DOES GENDER MATTER? 143

Kristína Kozová, Adriana Grenčíková¸ Martin Šrámka, Valentinas Navickas
UNDERSTANDING ACADEMIC SATISFACTION AMONG GENERATION Z: THE ROLE OF MENTAL WELLBEING AND INSTITUTIONAL EQUITY 160

Michal Varmus, Roman Adámik, Michal Šarlák, Jana Rádiková, Radovan Bryndza, Andrej Oršula
EDUCATION AND CAREER TRANSITION OF ATHLETES: A COMPARATIVE ANALYSIS OF FORMER AND CURRENT ATHLETES IN SLOVAKIA 175

Zuolong Ye, Alexander A. Hernandez, Yulin Chen, Dongdong Liang
FOUR-STAGE INCUBATION MODEL FOR UNIVERSITY INNOVATION AND ENTREPRENEURSHIP INCUBATOR: AN EMPIRICAL STUDY 188

Kristína Kozová, Adriana Grenčíková, Jozef Habánik, Valentinas Navickas
GENERATIONAL PREDICTORS OF JOB SATISFACTION IN THE CONTEXT OF FLEXIBLE WORK ARRANGEMENTS 207

Jakub Horák
CAPITAL MARKET BEHAVIOR AND STOCK FORECASTING – A NEURAL NETWORK APPROACH TO LUFTHANSA´S SHARES 222

Jana Španková, Jana Sochuľáková
THE USE OF ARTIFICIAL INTELLIGENCE IN HUMAN RESOURCE MANAGEMENT OF ENTERPRISES 238

Jozef Kučera
INNOVATION PERFORMANCE AS A SIGNIFICANT FACTOR IN THE CONVERGENCE PROCESS OF THE V4 COUNTRIES 250

Lukas Vartiak, Miroslav Skoda, Daniel Lajcin, Katarina Izova, Saroj Kumar Sahoo, Tushar Ranjan Sahoo
DRIVERS OF FRONT-LINE SALES EMPLOYEES' RETENTION: INTERACTION, MOTIVATION, AND PERFORMANCE 264

Weibo Zhou, Anatolijs Krivins, Valters Kaze
MANAGEMENT IN REAL ESTATE: POWERED BY DIGITAL TWINS 280

Vladimir Menshikov, Oksana Ruza, Jurijs Baltgailis
THE DIGITAL TRANSFORMATION AND THE INCLUSIVE ECONOMY: NAVIGATING THE RISKS 299

Heinzová Romana, Hoke Eva
SUSTAINABILITY AND GREEN MANAGEMENT IN HOSPITALS 313

Valavadra Sahu, Saroj Kumar Sahoo, Simran Babu, Sandhyarani Sahoo, Juraj Fabus, Miriam Garbarova
THE RELATIONSHIP OF CONTENT AND AFFILIATE MARKETING STRATEGIES WITH VARYING SHOPPING BEHAVIOURS 325

Emília Duľová Spišáková, Janka Majerníková
BRIDGING GLOBAL AND EUROPEAN AGENDAS: AN EVALUATION OF PROGRESS ON SDG 4 AND THE EUROPE 2020 STRATEGY 340

Damian Dubis, Andrzej Chochół, Jacek Czerniak
TOWARDS MORE SUSTAINABLE CONSUMPTION VIA QUALITY MANAGEMENT OF GLASSWARE WASHING 356

Dana Jašková, Katarína Kráľová
CUSTOMER PERCEPTION OF AI-SUPPORTED COMMUNICATION IN INSURANCE: A RAPID REVIEW 372

Halyna Kryshtal, Iryna Lytovchenko, Inga Bumane, Svitlana Labunska, Ľubica Filipova
MODELLING THE IMPACT OF FINANCIAL SERVICES DIGITALIZATION ON ACHIEVING THE GOALS OF SUSTAINABLE ECONOMIC DEVELOPMENT 386

Viktoriia Hrosul, Volodymyr Yermachenko, Serhii Zubkov, Alina Kolesnyk, Marek Semerád
ENTERPRISE DIGITAL RESILIENCE CAPABILITY FRAMEWORK: AN INTEGRATED DYNAMIC CAPABILITY APPROACH 399

Olena Rayevnyeva, Volodymyr Ponomarenko, Kostyantyn Stryzhychenko, Olha Brovko, Ľubica Filipova
MODELS OF INTERACTION BETWEEN ECONOMIC DEVELOPMENT AND HIGHER EDUCATION 417

Margarita Išoraitė, Gediminas Dubauskas
ROLE OF BLOCKCHAIN TECHNOLOGY IN GREEN BANKING 440

Nam Danh Nguyen, Lan Ngoc Thi Uong
INTENTION TO PAY FOR ENVIRONMENTAL SERVICES: A CASE STUDY OF TOURISM ENTERPRISES IN THE MEKONG DELTA, VIETNAM 451

Patrik Boršoš, Iveta Dirgová Luptáková, Ladislav Huraj, Darja Gabriška
ACCEPTANCE OF ARTIFICIAL INTELLIGENCE TECHNOLOGY IN THE RECRUITMENT PROCESS OF SLOVAK ENTERPRISES 464

Nam Danh Nguyen
FACTORS AFFECTING DIGITAL ENTREPRENEURSHIP: A CASE STUDY OF VIETNAMESE WOMEN 478

ENTREPRENEURSHIP AND SUSTAINABILITY ISSUES
ISSN 2345-0282 (online) http://jssidoi.org/jesi/
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MANAGEMENT OF SCIENCE AND TECHNOLOGY PARKS IN POLAND*

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Abstract. The aim of the article is to present the specific nature of managing Science and Technology Parks (Parks, STPs) in Poland in the context of using the Business Process Management (BPM) concept there and to identify key organizational factors that facilitate or impede the implementation and development of BPM in these entities. A quantitative research approach was used, employing a structured questionnaire based on the tool presented in the PRI method, adapted to the specific context of Polish STPs. Data were collected from 56 respondents across 28 Parks. Statistical analyses, including Pearson's correlation, were applied to examine the relationships between the advancement of using BPM (i.e. process maturity) and selected organizational characteristics. The results show that most STPs are positioned at intermediate process maturity levels (levels 2 and 4), while only a small proportion reach the highest, 5th level. A significant positive correlation was found between the number of tenant enterprises and process maturity, indicating that organizational complexity drives the need for formalized processes. Other variables, such as year of establishment and employee count, showed no significant effects. The findings provide managers of STPs with actionable insights, including the importance of using maturity models for self-assessment, investing in ICT systems to support BPM and strengthening HR strategies, particularly to equip employees with competencies needed in dynamic and flexible organizational settings. This research contributes to the relatively scarce literature on BPM in STPs, particularly within the Central and Eastern European context. It offers novel empirical evidence on the factors influencing process maturity and delivers practical recommendations for managers and policymakers aiming to enhance process-based management in innovation-driven organizations.

Keywords: Business Process Management; process maturity; a Science and Technology Park; STPs' characteristics; managing STPs

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1. Introduction

Although the concept of Science and Technology Parks (STPs, Parks) has gained worldwide popularity, there is still no universally accepted definition that captures their full scope, functions and organizational characteristics (Hobbs et al., 2017; UNIDO, 2021). For the purposes of this paper, we adopt the definition provided by the International Association of Science Parks and Areas of Innovation (IASP), which describes STP as an organization managed by a specialized team, with the primary aim of enhancing community welfare by fostering innovation and competitiveness among its members. Building upon this definition, it can be assumed that STPs provide advanced and modern infrastructural mechanisms to facilitate the transfer of research findings into the economic sector. Their activities foster the emergence of knowledge spillovers and

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contribute to the intensification of economic growth at both regional and national levels. Thus, STPs play a pivotal role in creating an environment conducive to knowledge exchange, provide access to high-value-added resources and initiate and strengthen cooperation among entities operating within their structures (Martinez-Cañaz et al., 2011). Science and Technology Parks should be distinguished from the Technology Incubators. While Technology Incubators focus on supporting early-stage, mainly startup, technology-driven businesses with tailored resources and guidance, Parks, as previously mentioned, carry out a broader range of activities (Mohamed et al., 2024; Czaplińska & Romanowski, 2024).

Modern Parks are increasingly required to go beyond their traditional roles, offering new services and adopting innovative business models that support the emergence of new industries and sectors (IASP 2022; Lizińska et al., 2024; Xie, 2024; Forés & Fernández-Yáñez, 2024; Noronha & Pillai, 2025). In this evolving landscape, there is a growing recognition of the relevance of modern management concepts, including Business Process Management (BPM). BPM, which gained prominence in Poland in the 1990s, involves structuring organizations around processes that are aligned with strategic goals and customer expectations (Bitkowska & Łukaszczuk-Walter, 2022). A core concept within BPM is process maturity, which reflects the extent to which an organization has adopted and developed process-oriented management practices. As noted by Brajer-Marczak and Gębczyńska (2020), moving from lower to higher levels of process maturity first improves the performance of individual processes, then enhances business functions and eventually leads to transformation at the organizational level. Numerous other authors also point out the correlation between increasing process maturity levels in organizations and their performance outcomes, while empirical evidence is given here by e.g., Mc Cormack and Johnson (2001), as well as Kohlbacher and Reijers (2013). Accordingly, it may be inferred that attaining higher levels of process maturity contributes to increased customer satisfaction, enhanced product quality, a more favorable organizational climate, a reduction in internal conflicts and greater coherence and alignment in organizational activities (McCormack & Johnson, 2001; Kohlbacher & Reijers, 2013). This suggests that pursuing process maturity may constitute a valid strategic direction for the development of Parks, enabling these entities to operate with greater flexibility, efficiency and stronger focus on value creation. However, studies on the application of BPM in STPs remain limited, and a clear research gap persists regarding the assessment of their process maturity. It is therefore justified to undertake in-depth investigations to determine the extent of BPM adoption in Parks and to identify the factors that influence the attainment of higher levels of process maturity of STPs.

Thus, the aim of the research presented in the paper was to examine the level of process maturity of Science and Technology parks in Poland and to identify the factors that foster or hinder the development of Business Process Management in those entities.

The structure of the article includes a literature review on BPM and STPs, a description of the applied research methodology, the presentation and analysis of empirical findings and their discussion. The paper concludes with recommendations for further research and suggestions for implementing process-oriented approaches in the management of Parks.

2. Theoretical background

Business Process Management, as a comprehensive idea, became widespread in both academic and business practice at the turn of the 1980s and 1990s, that is, in the period that in management science is often referred to as the *"era of reengineering"*. Although its origins can be traced back much earlier, i.e. when the representatives of the Scientific Management movement aimed their research efforts at developing methods for effective process management and even earlier - by Smith, who in his 1776 work *The Wealth of Nations* presented an analysis of the production process of pins and nails, but it was during the *"era of reengineering"* period that Hammer and Champy (1996) shaped and formalized the concept by giving it a defined theoretical and practical framework (Hammer & Champy, 1996; Lusk et al., 2005; Senkus et al., 2021).

It is impossible to consider BPM without first defining the essence of a business process and outlining the key assumptions underlying this concept. The literature offers numerous definitions of the term *business process*, and some of the first consistent clarifications emerged during the rise of the BPR movement. For

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example, Pall (1987) described a process as *the logical organization of people, materials, energy, equipment and procedures into work activities designed to achieve a specific "end" result*. As previously mentioned, Hammer and Champy (1996) defined the construct as *a set of activities that uses one or more kinds of input and creates an output that has value for the customer*. In later years, processes began to be defined with a lower level of generality (Senkus et al., 2021). For instance, the Object Management Group - the creators of one of the most widely adopted organizational process maturity models - described a process as *a defined set of business activities representing the steps required to achieve a business objective*. It includes the flow and use of information as well as other resources (Object Management Group, 2011). Regardless of the adopted definition, organizations establish processes to ensure the achievement of their business objectives while complying with relevant laws and regulations.

The concept of BPM has been also conceptualized and defined in numerous ways. Moreover, Nowosielski (2008) and Silva et al. (2022) argue that it should be viewed more broadly than merely as a concept, advocating the perspective that it is, in essence, a management orientation or philosophy. A similar view is shared by Bitkowska (2021) and Bandara et al. (2021a), who indicate that the concept in question can be regarded as a holistic and comprehensive approach to managing organizations. This does not change the fact, however, that the literature contains numerous attempts to define BPM. Most of the existing clarifications refer directly to the management of processes carried out within organizations, treating processes as a key aspect and the core of the concept**.** For example, Brilman (2002) defines BPM as a *systematic evaluation of processes and their outcomes, aimed at maintaining their functioning and making adjustments when the achieved results deviate from the standards*, while Dumas et al. (2018) emphasize that one of the fundamental principles of BPM is the definition and analysis of business processes**,** which includes mapping the activities involved, identifying potential bottlenecks or other inefficiencies and determining how the process can be improved - that is, optimized. Thus, one of the primary goals of implementing BPM in organizations is to develop a management model that ensures a sustainable competitive advantage and enables improved performance across various functional areas (Reijers, 2021).

Considering the research topic addressed in the article, particular attention should be paid to the characteristics of process maturity. It refers to the extent to which an organization's processes are defined, managed, measured, controlled and continuously improved over time, reflecting how well an organization understands, governs and optimizes its internal processes to achieve strategic objectives (Hammer, 2007). With the increasing complexity of managing modern organizations and growing expectations from their stakeholders, tools that enable professionalization and alignment of internal operations are gaining importance (Khorshid et al., 2023). In this context, the concept of process maturity emerges as a critical framework for assessing internal organizational capabilities. Moreover, it not only allows for diagnosing the current state of operations but also supports development planning, the implementation of IT systems and the cultivation of a culture of continuous improvement (Paulk et al., 1993; Rosemann & de Bruin, 2005; Fuschi & Galiyeva, 2022).

Organizations can measure their process maturity using various models and tools, which provide insights into the current state of their processes and guide improvement efforts (Mielcarek, 2020; Gökalp, 2020). Thus, following Brajer-Marczak (2017), process maturity can be also understood as the degree to which the guidelines outlined in a selected process maturity model have been implemented within an organization. The attainment of successive levels of process maturity is influenced by a range of factors. Implementation and development of BPM in organizations is primarily determined by technological, individual, organizational, social and strategic factors. Among the technological determinants, the most indicated are not only the level of use of information and communication technology (ICT), but also its perceived usefulness and ease of use (Eikebrokk et al. 2011). Additionally, the presence of appropriate ITC systems supporting processes, such as workflow systems or tools for monitoring process performance indicators, is crucial for achieving BPM goals (Pypłacz, 2022). Individual factors include, among others, self-assessed efficacy in process modeling and employees' overall process awareness. Both variables influence attitudes toward BPM and are linked to the willingness to implement changes (Eikebrokk et al., 2011). In the public sector, professional experience and the scope of an employee's responsibilities also prove to be significant, as they shape the individual's perception of BPM culture (Ahmad & van Looy, 2021; Kregel et al., 2021). Organizational determinants include the size of the organization, which affects the availability of resources for process implementation, as well as the degree of formalization of the process owner role and the clarity of process objectives (Pypłacz, 2022). Dijkman et al.

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(2016) present a strong argument regarding the impact of organizational size on process maturity. According to their research, larger organizations are better positioned to implement and develop BPM due to their greater availability of resources. Moreover, the complexity inherent in large-scale operations creates a pressing need for clearly defined and well-structured processes, as a lack of formalization can lead to inefficiencies and management challenges. Additionally, organizations with a higher number of employees tend to document their business processes more thoroughly and exhibit a greater degree of standardization across various departments (Dijkman et al., 2016; Vijayakumar, 2023). Organizational determinants may also include factors such as the age of an organization. Organizational life cycle theories suggest that as organizations age, they tend to move from informal, innovative structures toward more formalized, stable and process-oriented ones. This progression aligns with increasing levels of BPM maturity. Studies by Quinn and Cameron (1983), as well as others, support a potential positive relationship between organizational age and process maturity. The level of process maturity also depends on the presence of an organizational culture that promotes, among others, responsibility, collaboration and customer orientation (Glambek et al., 2023; Aljlayel, 2024). However, in public administration, additional limitations arise here, such as regulatory rigidity and the dominance of bureaucratic culture, which hinder the implementation of flexible BPM models (Espinheira & Almeida 2021; Raczyńska & Krukowski 2022). In terms of social determinants, subjective norms, namely the expectations of supervisors, co-workers and clients, play an important role by exerting pressure on employee behavior (Eikebrokk et al., 2011; Frank et al., 2020). Finally, among strategic determinants, the alignment of organizational strategy with process architecture and a strong orientation toward both external and internal customers are emphasized. In the public sector, this aspect requires particular attention, as service recipients often simultaneously act as co-creators of value (Kregel et al., 2021). The above determinants do not constitute an exhaustive list of the conditions necessary for the implementation and advancement of BPM within organizations. Rather, the effectiveness of BPM is contingent upon a multifaceted interaction of technological, human, cultural and structural factors, the significance of which is context-dependent and varies across organizational settings (Chen et al., 2021).

Process maturity can be assessed for any type of organization or industry, including Science and Technology Parks. Although the BPM approach is widely applied across both the private and public sectors, its implementation within STPs remains relatively new and underexplored. This underscores the need for in-depth empirical research to better understand the levels and variations of process maturity among Parks operating within diverse cultural and institutional contexts.

The use of BPM in STPs is beginning to attract attention in the literature, however, the topic has yet to receive substantial scholarly focus. In the context of organizational development within these entities, the integration of BPM and Enterprise Architecture (EA) is increasingly recognized as a foundational theme in academic discourse. EA is broadly defined as a strategic and holistic framework that facilitates the alignment of an organization's processes, information systems and strategic objectives (Lankhorst, 2009). It serves not only as a blueprint for organizational structure and technological infrastructure but also as a catalyst for coherence, agility and responsiveness in complex, knowledge-intensive environments. In the context of Parks, EA provides the structural foundation for integrating management processes and technological support systems. This alignment is particularly critical given the multifaceted roles these entities play in fostering entrepreneurship, facilitating technology transfer and supporting startup growth (Correia et al., 2021).

Among tools applied to evaluate and enhance such alignment, process maturity models**,** notably the Process and Enterprise Maturity Model (PEMM) introduced by Hammer (2007), have gained prominence. PEMM provides a multidimensional framework that distinguishes between process enablers (such as design, execution, ownership, infrastructure and metrics) and organizational capabilities (including leadership, culture, expertise and governance) (Piana et al., 2023). These components collectively facilitate a granular analysis of how well a given organization manages its internal processes and adapts to strategic demands. Empirical studies in Latin America, for example, reveal that while many STPs operate at intermediate maturity levels (typically level 3), there remains significant variability and potential for targeted process improvement (Correia et al., 2021). In response to these findings, Correia and da Veiga (2019) proposed a process-based management model explicitly designed for the Parks. Their model advocates for the structured integration of business processes with customized information systems, grounded in the principles of EA. It also emphasizes the importance of coherence between process workflows and digital infrastructures to support dynamic management and strategic

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flexibility. Despite the existence of a few studies addressing the level of process maturity in STPs, the available literature remains limited both in terms of the number of publications and the scope of topics covered. These studies rarely explore the conditions that facilitate the enhancement of process orientation within these entities. Meanwhile, given the significant role that STPs play in economic development, identifying the drivers and barriers to implementing concepts that can support their effective functioning becomes particularly important.

3. Methods

The study aimed at identifying the level of process maturity of Polish Science and Technology Parks was conducted between May and July of 2024. The survey technique employed was a structured questionnaire comprising 16 questions related to various aspects of the Parks' advancement in implementing BPM. The questionnaire was developed based on the Process Maturity Assessment Tool created in 2015 as part of the Institutional Development Planning (PRI) project (Żabiński, 2015). The tool enables the classification of entities into one of five levels of process maturity, with each level described by a set of distinct conditions (criteria). Its important aspect is the application of the cumulative principle, which means that to advance to a higher level of process maturity, it is necessary to fulfill all the requirements of the preceding level. Recognizing that process maturity models offer valuable frameworks for organizations to enhance their processes, it is important to acknowledge that these models are not one-size-fits-all solutions. Therefore, the tool was adapted to the unique contexts of functioning and business needs of the surveyed entities. The questionnaire targeted employees of STPs, with two respondents from each entity.

As a result of the conducted study, 56 correctly completed survey questionnaires were obtained from 28 entities, in which respondents assessed specific statements in terms of their occurrence within the STP. With the total number of STPs in Poland at the level of 34, this results in a return rate of 82%. This provided a basis for determining the level of process maturity of the surveyed Parks.

The STPs under analysis were examined in terms of their size (number of employees), number of tenant enterprises and year of establishment (Table 1). Therefore, the analysis focused primarily on determinants of process maturity related to the before mentioned organizational factors. Most of the Parks represented relatively small-scale institutions, employing no more than 20 individuals, which may indicate a predominantly local or regionally limited scope of operations. A comparable trend is observed regarding the number of tenant enterprises - over half of the Parks accommodated no more than 50 organizations, further suggesting a modest scale of activity. The period between 2001 and 2010 emerges as a particularly dynamic phase in the development of such entities, likely attributable to increased policy and funding initiatives aimed at fostering entrepreneurship during that decade. The limited number of STPs established prior to the year 2000 reflects the relatively recent emergence of this sector. At the same time, the continued establishment of new Parks after 2010 points to a sustained demand for their presence and function within the broader economic landscape.

Table 1. Profile of the examined Science and Technology Parks

Number of STPs' employees				
10 or fewer	11 - 20	21 - 40	41 - 60	61 or more
4 (14,3%)	10 (35,7%)	4 (14,2%)	6 (21,4%)	4 (14,3%)
Number of tenant enterprises in the STPs				
50 or less	51 - 100	101 - 150	151 - 200	201 or more
14 (50,0%)	9 (32,2%)	2 (7,1%)	1 (3,6%)	2 (7,1%)
Establishment year of STPs				
2000 or earlier		2001-2010	2011 or later	
3 (10,7%)		17 (60,7%)	8 (28,6%)	

Source: own work based on the conducted study

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2025 Volume 13 Number 2 (December)
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Considering the potential for common method bias (CMB), the questionnaire design employed the split-sample approach proposed by Brewer (2006). This method aimed to mitigate CMB by using one group of respondents to assess the independent variable and another to assess the dependent variable. In the presented study, the independent variables, namely the number of employees working in the Park (in persons), the number of tenant enterprises and the year of park establishment, were based on administrative data (Podsakoff et al., 2012; Jakobsen & Jensen, 2015). The survey was directed at two individuals within each organization who possessed knowledge of BPM, which further reduced the risk of measurement error (MacKenzie & Podsakoff, 2012). To minimize bias, respondents were selected based on their sufficient domain expertise, ensuring that the responses would not be affected by ambiguity in the questionnaire. Additionally, the questions referred to the current situation of the organization, which further helped in reducing the risk of systematic error.

To assess the internal consistency of the variables describing the factors associated with process maturity, the Cronbach's alpha reliability coefficient was computed. The resulting value of $\alpha = 0.788$ indicates a satisfactory level of internal reliability, thereby confirming the coherence of the constructs adopted for evaluation. The authors acknowledge the intercorrelated nature of the selected factors, however, the primary objective of the study was not to examine the interdependencies among these variables, but rather to determine their presence and evaluate them in relation to the process maturity characteristics attributed to each Park. This interrelation is justified, as the constructs pertain to a common underlying phenomenon.

To explore potential associations between the level of process maturity in STPs and their descriptive characteristics, Pearson's product-moment correlation analysis was employed. A significance threshold of $\alpha = 0.05$ was established for the purposes of statistical inference. All computations were conducted using IBM SPSS software.

The conducted study presents several important limitations that should be considered when interpreting the results. First, the research covered 28 parks and 56 respondents, which, despite the purposeful selection of the sample, does not allow for full generalization of the findings to the entire population of STPs in Poland, let alone in an international context. Additionally, although an adapted version of the assessment tool developed under the PRI project was applied, the study relied solely on one model of process maturity assessment. The lack of alternative frameworks, such as CMMI or PEMM, limits the potential for comparison and may narrow the evaluative perspective.

It should also be noted that the study primarily focused on internal characteristics of the Parks, such as the number of employees, number of tenant enterprises and the year of establishment. However, it omitted external and contextual factors that may significantly influence the development of process orientation, including regional policy, institutional support, funding availability or the degree of linkage with the public and academic sectors. All these limitations highlight the need for further, in-depth research (both quantitative and qualitative) that would allow for a better understanding of the mechanisms influencing process maturity of STPs and for the development of effective strategies aimed at enhancing it.

4. Research results

The analysis provides a comprehensive overview of the distribution of STPs across various levels of process maturity. It incorporates, as it was mentioned, key organizational characteristics, including the year of establishment, the number of employees and the number of tenant enterprises. These data, presented in Table 2, aim to support a deeper understanding of how the selected organizational factors correlate with the developmental stages of process maturity.

Overall, the highest number of Parks is found at level 2 (11 STPs) and level 4 (10 STPs), indicating that most of the examined entities are situated at an intermediate stage of process maturity. Levels 1, 3 and 5 are less represented, with 1, 3 and 3 Parks respectively.

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Table 2. An analysis of the relationship between selected characteristics of STPs and their process maturity levels: a quantitative perspective (n=28)

Specification		Process maturity level				
		L1	**L2**	**L3**	**L4**	**L5**
In total		1	11	3	10	3
Year of establishment	2000 or earlier	0	2	0	1	0
	2001-2010	1	5	3	5	3
	2011 or later	0	4	0	4	0
Number of employees	10 or less	0	3	1	0	0
	11-20	0	3	1	5	1
	21-40	0	2	1	1	0
	41-60	1	0	0	3	2
	61 or more	0	3	0	1	0
Number of tenant enterprises	50 or less	1	6	1	5	1
	51-100	0	4	2	3	0
	101-150	0	0	0	1	1
	151-200	0	0	0	1	0
	201 or more	0	1	0	0	1

L – stands for "level".

Source: own work based on the conducted study.

One of the key differentiating factors in determining the level of maturity appears to be the year of establishment. Parks founded between 2001 and 2010 dominate across all process maturity stages and tend to reach its highest levels. In contrast, Parks established in 2011 or later, are mainly present at levels 2 and 4, while those founded in 2000 or earlier, are few and generally exhibit lower levels of maturity. The number of employees in Parks also influences the distribution of process maturity levels. Units employing between 11 and 20 individuals display the greatest diversity and are notably represented at levels 2 and 4. Larger Parks, with staff numbers ranging from 41 to 60, demonstrate the highest levels of process advancement, reaching maturity levels 4 and 5. Likewise, the number of tenant enterprises appears to be significant determinant of process maturity levels. Parks hosting a smaller number of tenants (50 or less) are predominantly represented at levels 2 and 4. Those with a medium-sized tenant base (51 to 100) are distributed across all maturity levels, with a notable concentration at level 2. The largest STPs, accommodating 100 tenant enterprises or more, are exclusively found at levels 4 and 5, suggesting a strong capacity for managing complex organizational structures and processes.

The analysis of the relationship between STPs' characteristics and their process maturity is presented in Table 3. It was evaluated with the use of Pearson's correlation coefficient and significance testing.

Table 3. The relationship between the characteristics of STPs and their process maturity

Specification	Process maturity level	
Year of establishment	Pearson's correlation coefficient	0,05
	(one-tailed significance)	0,358
Number of employees	Pearson's correlation coefficient	-0,046
	(one-tailed) significance	0,367
Number of tenant enterprises	Pearson's correlation coefficient	0,256*
	(one-tailed) significance	0,028

* Correlation significant at the 0.05 level.

Source: own work based on the conducted study.

Based on the analysis, the correlation between the year of establishment of the Park and its process maturity level is very low (r = 0.05) and statistically insignificant (one-tailed significance = 0.358). Similarly, the correlation between the number of employees and process maturity is also low and insignificant (r = -0.046; one-tailed significance = 0.367). These results suggest that neither the year of establishment nor the number of employees significantly influence the process maturity of the STPs.

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2025 Volume 13 Number 2 (December)
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In contrast, the number of tenant enterprises shows a moderate positive correlation with process maturity (r = 0.256), which is statistically significant at the 0.05 level (one-tailed significance = 0.028). This indicates that a higher number of tenants may be moderately associated with greater process maturity, suggesting a meaningful impact of this variable on the efficiency of processes within the Parks. Therefore, the findings indicate that characteristics such as the year of establishment and the number of employees do not play a crucial role in determining the process maturity of the Parks, whereas the number of tenant enterprises may have a significant influence here.

5. Discussion

The results of the presented study provide insight into the process maturity level of Science and Technology Parks in Poland, indicating both its status and the areas that require further development. The dominance of Parks at levels 2 and 4 of process maturity suggests that, although the basic elements of BPM have been implemented in many entities, there is a significant gap between initial implementation and the full institutionalization of the discussed concept within these organizations. Concern is raised by the very low representation of Parks at the 3rd stage of process maturity. The results obtained may be a consequence of the design and assumptions of the research tool used, primarily the cumulative requirement. Transitioning from level 2 to level 3 required STPs not only to develop detailed descriptions of key processes (including indicators and their implementation stages), but also to train process owners and other participants in BPM, establish methods for documenting process execution and carry out regular process risk management activities. An analysis of the Parks' responses regarding the presence of these elements revealed that most entities encountered difficulties at the stage of developing detailed descriptions of key processes. Studies in the literature indicate that the success of business process modeling initiatives, including the development of process descriptions, is significantly influenced by a combination of factors such as top-level management support, project management capabilities, stakeholder engagement, modeling expertise and the effective use of ITC-based modeling tools (Bandara et al., 2021b). Considering these findings, it can be inferred that STPs may encounter a variety of challenges when attempting to develop comprehensive and detailed descriptions of their key processes. Firstly, many of these entities operate within project-based environments, where activities are highly tailored to client needs. This complexity hinders the structuring of operations into repeatable processes with clearly defined indicators and stages (Frank et al., 2020; Vijayakumar, 2023). Secondly, a lack of a standardized approach to process identification often leads to uncertainty regarding which activities should be classified as key processes. It is also worth noting that contemporary service design practices conceptualize services as multi-stage processes in which the value of each step is uncertain and influenced by both functional benefits and subjective user experiences (Bellos & Kavadias, 2021). This prevailing uncertainty may lead to the avoidance of efforts aimed at describing key processes within STPs. Additionally, such initiatives are often perceived as superfluous bureaucratic procedures, which can act as a barrier to their implementation. This perception is further associated with the risk of bureaucratic dysfunctions, including delayed decision-making, reduced transparency and increased operational costs (Espinheira & Almeida, 2021; Setyasih, 2023). Without strong support from senior management, this issue may not be treated as a strategic priority. A key action in overcoming this perception may also be the promotion of a culture of accountability and transparency (Gardner & Childs, 2022).

It is also important to highlight the limited presence of STPs at the highest, 5th level of process maturity. According to the adopted assessment tool, reaching this stage requires the implementation of advanced practices across three interrelated areas. First, digital tools play a pivotal role here. As noted by Tsinarakis et al. (2022), Parks should utilize electronic systems that support process monitoring, performance tracking through indicators and process modeling using maps and workflows. The implementation of such ITC systems in a technologically advanced and smart STP demonstrates its ability to deliver personalized project solutions and enables integrated, professional management, thereby creating greater economic and social value (Zhang & Li, 2023). Second, continuous process improvement must be grounded in data, including the use of customer satisfaction surveys and process monitoring to enhance efficiency, quality and timeliness. Continuous improvement also entails the regular assessment of all tools and procedures related to BPM, along with the systematic use of these assessments to inform improvements. Third, mature process management presupposes strategic learning through external comparisons. Parks should therefore engage in ongoing benchmarking of

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their processes and organizational practices against other STPs and proactively adopt and implement proven practices from recognized leaders in the field. A more in-depth analysis in this area revealed that the studied entities primarily suffer from a lack of technological infrastructure necessary for mature process management. The insufficient use of ITC systems supporting BPM in Parks can be attributed to a combination of various factors. First and foremost, the implementation of tools such as BPM systems or software for process modeling and monitoring entails high costs, not only in terms of license acquisition, but also in adapting the systems to the specific context of the Parks functioning, implementing them effectively and providing adequate training for the employees. Reducing this barrier could yield significant benefits, as current research shows that the implementation of process monitoring systems leads to a reduction in organizational operating costs, including lower energy consumption, making it a potentially more efficient solution for monitoring STPs than other non-process-based systems (Chen et al., 2021). Despite the advantages associated with the adoption of ITC systems supporting BPM in Parks, for many of these entities, particularly those operating with public funds or project-based financing, such expenditures are difficult to justify or may be ineligible under existing funding mechanisms (Entringer & Lacopo da Silva, 2020). For instance, many university-affiliated Research and Science Parks, especially those funded primarily through public sources, face challenges in justifying expenses related to economic impact assessments (Hobbs et al., 2020). Moreover, there is often a lack of awareness within Science and Technology Parks regarding the necessity of using such tools, as they are frequently perceived as overly complex, unintuitive, excessively sophisticated or simply not useful for day-to-day operations. This perception may therefore result in low interest in their adoption (Zuhaira & Ahmad, 2021; Zhou et al., 2023).

Another noteworthy finding is the statistically significant, moderately positive correlation between the number of tenant enterprises and the process maturity level of STPs. This result suggests that an increase in the number of tenants may act as a catalyst for the formalization and standardization of processes, thus, enhancing process maturity. It supports the theoretical proposition that growing organizational complexity heightens the need for systematic management tools (Dijkman et al., 2016) and aligns with the conclusions of studies conducted in Latin America (Correia et al., 2021). While a higher number of tenants may foster more efficient collaboration and resource sharing, there is currently no direct evidence confirming that formalization and standardization processes are taking place specifically within STPs (Albahari et al., 2022). In contrast to the findings, neither the year of establishment nor the number of employees showed a statistically significant relationship with the process maturity level of STPs. This result contradicts earlier research suggesting that organizational age and size positively influence BPM development (Quinn & Cameron, 1983; Pypłacz, 2022). A possible explanation is that the development of Science and Technology Parks in Poland has occurred relatively recently and within a similar political environment, which may have minimized differences attributable to age and workforce size. But, for example, a study focusing on public sector organizations in the United Arab Emirates found that larger entities demonstrated more robust knowledge management processes, which are closely linked to the effectiveness of BPM. However, it should be noted that these benefits may be offset in very large organizations due to their inherent complexity and bureaucratic inefficiencies (Al Yami et al., 2022).

All these observations confirm the need to develop personalized, context-sensitive strategies to support BPM in Science and Technology Parks. In this matter, greater attention should be devoted to the role of external factors, such as public policy support and regional innovation ecosystems, as well as internal enablers of BPM development, including leadership, governance structures, continuous training in BPM practices and investments in dedicated ITC infrastructure. Finally, the adoption of integrated models such as the earlier mentioned Process and Enterprise Maturity Model, which consider both process elements and organizational capabilities, may offer a pathway to reducing the current disparities in process maturity levels among different STPs.

Conclusions

The conducted study provides a basis for concluding that most of the Science and Technology Parks in Poland have reached levels 2 and 4 of process maturity, indicating their moderate advancement in the use of BPM. Parks that have achieved the highest level of maturity (level 5) represent a minority, which suggest challenges in fully implementing advanced process solutions within these entities. A key factor found to play a significant role in increasing the level of process maturity was the number of tenant enterprises in Parks.

The study also indicates that the year of establishment and the number of employees in STPs do not have a significant impact on the level of their process maturity. In contrast, the number of tenant enterprises, as it was mentioned, shows a moderately positive influence on this level, which may suggest that larger structures are more capable of adapting advanced processes. Furthermore, serving a greater number of tenant enterprises may create a need to organize work more efficiently and implement specific process execution procedures, thereby contributing to increased process maturity in these entities.

Based on the obtained research results and its limitations, several directions for further studies can be identified. First, as it was mentioned, the results of the study indicate that a considerable number of STPs remain at level 2, with relatively few reaching level 3. Although the study results revealed factors that may play a decisive role in this regard, the authors believe that further, in-depth analysis is still required. Therefore, it is justified to investigate the key factors within e.g. STPs' organizational culture, their work structure or the factors related to their strategy etc., that may also limit progress to higher levels of process maturity. Such research could serve as a foundation for shaping development recommendations and targeted interventions to support process transformation in Parks. The analysis of the relationship between the characteristics of the Parks and their process maturity level revealed, as also previously mentioned, a statistically significant impact of only one variable, which is the number of tenant enterprises. Other factors proved to be statistically insignificant. Future research could delve deeper into the reasons behind this outcome. Moreover, some Parks achieve higher maturity levels despite having limited resources. Case study analyses could reveal which specific practices or strategies enabled these outcomes. Also conducting a longitudinal study involving the same entities in subsequent years would facilitate the assessment of the dynamics of change and the long-term effectiveness of implemented process-oriented practices. Furthermore, an in-depth analysis of the role of public policy and support instruments in promoting the development of process-based management could offer valuable insights and strategic recommendations for policymakers.

The conducted study carries several practical implications, primarily for the managers of STPs. First and foremost, the obtained results enable the identification of the level of advancement in BPM within individual Parks, which may serve as a starting point for designing targeted development activities both in these entities and in others that remain at lower maturity levels. In this context, the applied process maturity model can serve as a practical self-assessment tool, allowing for regular diagnosis of the organization's condition and the planning of appropriate improvements. Moreover, knowledge of the key factors influencing process maturity, such as the number of tenant enterprises, may support STPs' managers in making strategic decisions regarding organizational structure, human resource policies and investment directions. Finally, the findings may serve as an incentive to implement modern organizational models and ICT solutions that support process-oriented management and facilitate the attainment of higher maturity levels.

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IMPACT OF SOCIAL ECONOMY ORGANISATIONS ON ACHIEVING SUSTAINABLE DEVELOPMENT GOALS*

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Abstract. This scientific article explores the key role of social economy organisations as partners in achieving the Global Sustainable Development Goals. A new, integrated conceptual model for measuring and reporting impact is proposed that systematises existing concepts. The model encompasses four main components: theory (or theoretical basis for mission and impact), process (measurement cycle), method (tools), and reporting (report content and structure). This theoretical contribution provides a comprehensive framework for analysis that goes beyond traditional approaches. In contrast, the applied contribution offers practical guidance and concrete tools to increase the transparency and effectiveness of social organisations. Although it is a theoretical and qualitative study, the manuscript acknowledges its limitations, such as the lack of primary empirical data and the broad applicability of the model. It highlights the diversity in the social economy, which necessitates the adaptation of the model to the specific needs, resources, and context of the organisation. The study also emphasises that measuring impact is challenging but essential to avoid "*social washing*" and validate the long-term social and environmental value social organisations create. It concludes that the social economy has the potential to be a major driver of sustainable development, but this requires investment in capacity building, collaboration and the standardised measurement frameworks and reporting methods.

Keywords: social economy; organisations; social enterprises; sustainable development goals; impact; measurement

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1. Introduction

In September 2015, the United Nations adopted the 2030 Agenda for Sustainable Development, a universal call to action to end poverty, protect the planet and ensure prosperity for all. At the heart of this agenda are the 17 Sustainable Development Goals (SDGs), which are integrated and indivisible and aim to balance the three dimensions of sustainable development: economic, social and environmental. That means that the SDGs are not only comprehensive but also interrelated, calling for a holistic approach, in which progress in one area supports progress in others. This universality means that all countries, regardless of their economic status, not only have, but should take responsibility to act to achieve the goals (UN, 2015; de la Casa & Caballero, 2021; Samašonok & Išoraitė, 2023).

At the same time, in recent years, there has been an increased focus on the social economy, a concept that refers to a set of organisations whose primary purpose is not to make a profit, but to achieve *social, economic or*

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environmental results. As people increasingly understand that the current economic model based solely on growth is unworkable, the focus is shifting towards building a more sustainable and socially responsible economy (Berardi & Valentinetti, 2022; Vyas-Doorgapersad, 2024; Miszczak et al., 2025).

The social economy is driven by a variety of organisations, with different legal forms, including cooperatives, social enterprises, associations, foundations, and others. These organisations are governed by values and principles, such as the priority of the individual and the social purpose over capital; voluntary and open membership; democratic control by members; as well as autonomy and independence. The mission of these structures is to actively contribute to the creation of sustainable jobs, social integration and the development of local communities (EC, 2013; ILO, 2017; Lödar-Miculeac et al., 2024; Copello et al., 2023; Quilloy-Custodio et al., 2024; Meissner et al., 2024).

At the same time, there is considerable diversity in the terminology used in the scientific literature to refer to organisations that combine a social mission with economic activity. The same entities are often referred to as *social organisations*, *social enterprises* or *social economy organisations*. The differences reflect the specific context, focus or legal framework in which these organisations operate. In this article, the term *social economy organisation* (SEOs) will be used as the preferred term, as it is the most comprehensive and includes all entities that are part of the larger social economy ecosystem. This choice aims to ensure precision and clarity while highlighting the scale and diversity of the entities under consideration.

It is important to note that SEOs are natural partners in achieving the SDGs, as their core principles and goals are directly aligned with the essence of the sustainable development agenda (de la Casa & Caballero, 2021). For example, social enterprises often focus on solving problems such as poverty (SDG 1), hunger (SDG 2), quality education (SDG 4) and decent work (SDG 8). Cooperatives strengthen the economic power of their members and support sustainable rural development, contributing to SDG 1 and SDG 8 (Berardi & Valentinetti, 2022). At the same time, associations and foundations often work for causes related to gender equality (SDG 5), reducing inequalities (SDG 10) and protecting the environment (SDGs 13, 14, 15). Their participatory and transparent governance model makes them ideal for building sustainable partnerships (SDG 17) (Quiroz-Niño & Murga-Menoyo, 2017; Venelinova & Beloeva, 2024).

Despite the apparent link between the social economy and the SDGs, the concrete contribution and impact often remain *unmeasured*. Moreover (and perhaps worse), they remain *underestimated*. The need to measure and report on this impact is crucial for several reasons (EC, n.d.; Ebrahim & Rangan, 2014; de la Casa & Caballero, 2021): *1) Demonstrate effectiveness*: Measurement provides concrete evidence of the social and environmental value created by these organisations, beyond their financial results; *2) Improve governance*: Impact data helps organisations themselves optimise their strategies and direct their resources more effectively towards achieving their missions; *3) Informing stakeholders*: Transparency about impact builds trust among partners, investors, clients and donors. *4) Developing public policies*: Concrete evidence on the contribution of the social economy can serve as a basis for developing more effective and targeted public policies and support programmes.

Therefore, it can be concluded that the need to measure and report the impact of SEOs on the SDGs is doubly motivated: *(1) organisational* – for better governance, access to finance and evidence-based decision-making; and *(2) systemic* – for transparency towards stakeholders and comparability of results in support of public policies. At the EU policy level, this requirement is materialised through the Corporate Sustainability Reporting Directive (CSRD) and the European Sustainability Standards (ESRS), which extend the mandatory disclosure of impacts, risks and opportunities and promote their connection to the SDGs (European Commission, n.d.; UNDP, 2021). Although not mandatory for SEOs, the CSRD and ESRS may have an indirect and voluntary impact on them. Large companies that are required to report under the CSRD will need to collect information from their entire supply chain, including from smaller companies or SEOs with which they work. At the same time, a number of social economy organisations may choose to apply the standards voluntarily to improve their transparency, attract investors or better position themselves in the market.

In parallel, international frameworks such as GRI (incl. “Integrating the SDGs into Corporate Reporting” and mapping between the SDGs and the GRI standards), the SDG Impact Standards of the United Nations

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Development Programme (UNDP) and the IRIS+ system of the GIIN offer methodological underpinnings for reliable impact measurement, management and reporting (GRI, n.d.; European Commission, n.d.; UNDP, 2021). Additionally, the Social Value International principles offer norms (e.g. stakeholder participation, understanding change, materiality and "*not overstating*") that are also applicable to the social economy (Social Value International, n.d.).

Thus, reporting on the specific contribution to the SDGs brings direct benefits, on the one hand, to SEOs (more straightforward strategy and impact management; access to capital and partnerships; trust among users and donors), to stakeholders (comparable and verifiable information on results and value for communities), and on the other hand, to public policies (better targeting of measures and resources to effective solutions) (de la Casa & Caballero, 2021). GRI empirical analyses show that an increasing number of organisations are structuring their reporting on the SDGs. Still, gaps remain in measurable commitments and evidence of results, which highlights the need for standardised approaches and independent evaluation (GRI, n.d.).

This article aims to synthesise and analyse existing methods and approaches for measuring and reporting the impact of SEOs on the achievement of the SDGs. Through a critical review of the scientific literature and existing frameworks, this paper will propose a systematised approach to measurement and reporting that practitioners and researchers can use in the field.

2. Methodology

The methodology applied in the development of this study can be defined as a qualitative, theoretical analysis based on a review of the scientific literature and empirical examples. It does not involve primary empirical research, but synthesises existing knowledge, frameworks and practices in the field of social economy and sustainable development. The main approach is to build a logical framework for understanding the relationship between SEOs and the SDGs by deconstructing key concepts and presenting real examples. The aim is not so much to collect new data, but to organise and interpret the available ones in order to propose a comprehensive and structured model for measuring and reporting impact.

The methodology of this study includes an extensive review of the literature, not limited to the traditional time range of 5 to 10 years. This broad perspective is necessary to trace the evolution of key concepts and theoretical foundations that are essential to the topic. By integrating classic and seminal works, the analysis gains depth and historical context, allowing for a more complete understanding of the current state of the field. This approach provides a solid theoretical framework that is a foundation for contemporary discussions and discoveries.

The choice of SEOs and the SDGs as the focus of the study is not accidental. It is based on the premise that these two concepts are fundamentally interconnected. SEOs are ideally suited to address complex, cross-cutting issues (Reinecke & Wrona, 2024) that underlie the SDGs – such as poverty (SDG 1), inequality (SDG 10) and decent work (SDG 8). Unlike commercial enterprises, they put social purpose before profit, making them natural agents for change. At the same time, the SDGs provide these organisations with a universal and legitimate framework for measuring their contributions, allowing them to communicate their value in a way that is understandable to the global community. This choice highlights the growing importance of the social economy as a development model that can balance economic growth with social justice and environmental sustainability.

3. Conceptual framework for measurement and reporting (*Theory, Process, Method, Report*)

3.1. Impact in the context of the social economy and the SDGs (*Theory*)

The concept of Social Economy

The concept of the social economy has developed dynamically over the last decade and has become established as an essential element of socio-economic systems in Europe and beyond. Within the European Commission, it is defined as a set of private and autonomous organisations that put people and the social purpose above profit

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and operate on the basis of democratic participation and reinvestment of surpluses for the benefit of society (EC, n.d.). A similar definition is also adopted by the OECD, which, in its Recommendation on the Social and Solidarity Economy and Social Innovation emphasises the unification of cooperatives, mutual societies, associations, foundations and social enterprises in a common field, the characteristic features of which are limited profit distribution, autonomy and a social mission (OECD, 2022). Contemporary academic literature confirms this consolidation of the concept and notes that, despite national differences, the terms "*social economy*" and "*social and solidarity economy*" are increasingly used as interchangeable frameworks, which indicates a process of conceptual convergence (Ruano et al., 2021).

At the same time, empirical data show the significant structural contribution of the social economy to employment and economic development. According to OECD research, around 6.2–6.3% of the workforce in the European Union is engaged in social economy organisations, which is an indicator of the stable role of this sector within European economies (OECD, 2023). A similar finding is also supported by VOLUNTAS analyses, which demonstrate both the quantitative growth of scientific publications in the field and the increasing relevance of the social economy in academic and political discourse (Benavides & Ehrenhard, 2021).

In recent years, particular attention has been paid to the relationship between the social economy and the UN SDGs. In resolution A/RES/77/281 of 2023, the UN General Assembly explicitly calls on States to develop the social and solidarity-based economy as a tool for achieving the SDGs, and the International Labour Organization in its resolution of 2022 emphasises its role in promoting decent work and social inclusion (UN, 2023; ILO, 2022).

Scientific research confirms these normative guidelines. Quaye *et al.* (2024) show that social enterprises, as part of the social economy, simultaneously address multiple goals through social innovation and partnerships, especially in the areas of poverty, health and sustainable cities. Similar conclusions are contained in the study by Catala et al. (2023), which analyses social value ecosystems and their role in supporting the SDGs by integrating entrepreneurial and innovation approaches.

The economic and social effects of the activities of social economy organisations are also evident in quantitative terms. Castro Núñez et al. (2020) present a study for Spain, which demonstrates, through the monetisation of social value, how social enterprises and cooperatives contribute to the implementation of the 2030 Agenda at the local and national levels. These results are in line with the analysis of Novkovic et al. (2022), who emphasise that the identity of cooperatives and their orientation towards a social mission are the basis of their ability to create added value for the community, not just economic profit.

Everything indicates that contemporary literature outlines the social economy as an increasingly recognised and conceptually consolidated sector that occupies a significant place in employment, demonstrates specific organisational models and represents a key channel for the implementation of the SDGs. The presence of unified definitions within international organisations, combined with peer-reviewed empirical evidence, allows us to argue that the social economy is not a peripheral, but a systemic element of sustainable development on a global scale.

Social Economy Organisations (SEOs)

Social economy organisations are a diverse and dynamic sector which differs from traditional commercial enterprises and the public sector. They are defined not only by their legal form, but also by their overarching purpose and governance (Quiroz-Niño & Murga-Menoyo, 2017). According to the European Commission and the Organisation for Economic Co-operation and Development (OECD), the social economy encompasses a wide range of private organisations (Table 1) whose primary purpose is not to make a profit but to achieve social, cultural or environmental outcomes (EC, 2013; European Commission. Internal Market, Industry, Entrepreneurship and SMEs, n.d.; Lödar-Miculeac et al., 2024).

These organisations often reinvest most of their earnings back into their mission rather than distributing them to shareholders and, despite their differences, share a common goal: to achieve social, cultural or environmental goals rather than to maximise profits. They operate on the principles of democratic governance, member

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participation, transparency and reinvestment of financial surpluses for public benefit, making them key players in achieving sustainable development and solving contemporary societal challenges (EC, n.d.; European Commission. Internal Market, Industry, Entrepreneurship and SMEs, n.d.; Lödar-Miculeac et al., 2024).

Table 1. Types of SEOs

Type of organisation	Key characteristics	Legislative framework / normative basis	Relationship with SDGs
Cooperatives	Democratic governance (one member, one vote), member participation, sustainable economic model, provision of services and products	Cooperative laws in individual countries; International Cooperative Alliance (ICA) *Case studies*: Agricultural cooperatives, consumer cooperatives, housing cooperatives	SDG 1 (Poverty), SDG 8 (Decent work and economic growth), SDG 11 (Sustainable cities)
Social Enterprises	A combination of a business model and a social mission, profits are reinvested for social purposes aimed at integration and inclusion	EU Social Enterprise Legislation; OECD Recommendations on Social Innovation *Case Studies*: Workshops for People with Disabilities, Recycling Enterprises	SDG 1 (Poverty), SDG 5 (Gender Equality), SDG 10 (Inequalities), SDG 12 (Responsible Consumption)
Associations and Societies	Voluntary and community initiatives, development of social services, cultural and educational activities	Law on Non-Profit Legal Entities; NGO Registration *Case Studies*: Local NGOs for education, sports clubs, cultural associations	SDG 4 (Education), SDG 11 (Sustainable communities), SDG 16 (Peace, justice and strong institutions)
Foundations	Funding social, cultural, health and educational projects; long-term societal impact	Foundation Law; Charitable Organisation Regulations *Case Studies*: Scholarship Foundations, Health Programs, Social Innovation	SDG 3 (Health and Well-being), SDG 4 (Education), SDG 10 (Inequalities)
Mutual societies	Principle of solidarity and mutual assistance, provision of services to members and the community, and a democratic structure	Law on mutual societies; EU Regulation on cooperative and solidarity-based structures *Case Studies*: Mutual insurance societies, housing mutual aid programmes	SDG 1 (Poverty), SDG 8 (Decent work and economic growth), SDG 10 (Inequalities)
Other non-profit forms	Public services, cultural initiatives, social and environmental innovations, oriented towards public value	NGO laws; Special regulatory regimes for social innovations *Case Studies*: Volunteer centres, social clubs, innovative environmental initiatives	SDG 3 (Health), SDG 7 (Clean energy), SDG 13 (Climate action), SDG 16 (Strong institutions)

Source: Author's development

Despite the identified similarity in objectives, the impact of SEOs is complex, long-term and difficult to quantify through traditional business indicators such as profit or market share (Quiroz-Niño & Murga-Menoyo, 2017). It is usually related to qualitative changes, such as improving the quality of life, social inclusion, promoting democratic processes and preserving cultural heritage. These changes are not easily measurable in monetary terms, which necessitates the application of specific, hybrid assessment approaches that combine quantitative and qualitative data and methods (Feor *et al.*, 2023). In this sense, the SDGs provide a universal, structured framework that can serve as a guide in measuring the impact of the social economy. Each SDG contains specific targets and indicators that allow organisations to focus their efforts and report their contributions in a unified way (UN, n.d.).

At the same time, in the ever-evolving field of social and environmental impact assessment, it is essential to distinguish between three key terms that are often used interchangeably but have different meanings: *output*, *outcome* and *impact*. This distinction is fundamental to understanding the real change that an organisation creates in society. In order to adequately assess the contribution of the social economy, it is essential to distinguish between the key terms:

- *Output*: refers to the immediate, quantitative products or services produced by an organisation. These are the direct, measurable activities that are carried out. For example, if a social enterprise offers a training program for the unemployed, the output would be the number of training sessions delivered, the number of people trained, or the number of certificates issued. Outputs are easy to measure, but they

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do not indicate whether the activity has had any real benefit or change for the target group (UNDP, 2016).

- *Outcome*: represents the changes in the behaviour, skills, knowledge, or status of the target groups that are a direct result of the products or services provided. In the context of a training program for the unemployed, outcomes may include participants increasing their skills, improving their confidence, or finding a job within a specific period. Outcomes are more challenging to measure than outcomes because they are often qualitative and require more in-depth research, such as surveys or interviews, to establish. However, they are more important because they indicate whether the organisation's activities have achieved their purpose (EC, 2013).
- *Impact*: the broadest and most complex term. It refers to the long-term, significant changes in society or the environment that occur as a result of the organisation's activities, taking into account other external factors. Impact is the net change, which can be either positive or negative, intended or unintended. For example, if a training program leads to a reduction in unemployment in a region or an increase in economic activity in the local community, this is already an impact. Measuring impact is challenging because it requires isolating the organisation's contribution from other factors, such as economic growth or changes in public policies (Social Value International, n.d.).

In the context of the social economy, this distinction is critical. Social enterprises and other organisations in the sector do not simply produce outputs (e.g., number of people fed or number of certificates issued), but seek to achieve long-term results and impacts, such as reducing poverty, improving health, or promoting social inclusion. Their mission is focused on system change, not simply on delivering a product or service. Therefore, assessing their impact requires methods that go beyond traditional financial metrics and should include qualitative and quantitative indicators of social and environmental change (de la Casa & Caballero, 2021; Berardi & Valentinetti, 2022). For this reason, the SDG framework is beneficial. It provides a global standard for what constitutes "*impact*." Each SDG and its associated targets and indicators serve as a map for measuring impact (UN, n.d.). Organisations can focus their efforts on specific SDGs, such as SDG 4 (Quality Education) or SDG 13 (Climate Action), and use official UN indicators as a starting point to define and measure their impact. This approach not only facilitates evaluation but also allows SEOs to demonstrate their contribution to the global goals in a transparent and unified way.

Link between SEOs and the SDGs

The link between the mission of SEOs and the SDGs is fundamental and multifaceted. It is not a mere coincidence, but is intrinsic to the social economy model. While the primary goal of traditional commercial enterprises is to maximise financial profit for their owners or shareholders, the mission of SEOs is aimed at achieving social, environmental or cultural value (Quiroz-Niño & Murga-Menoyo, 2017; Lödar-Miculeac et al., 2024). It is this essential difference that positions them as natural partners and drivers of the 2030 Agenda, since their main activities and objectives are directly aimed at solving societal problems that are at the heart of the SDGs.

This mechanism of direct correspondence can be illustrated through concrete examples. An organisation whose mission is to integrate people with disabilities into the labour market directly contributes to SDG 8 (Decent Work) and SDG 10 (Reduced Inequalities). Similarly, a cooperative created to support smallholder farmers is aligned with SDG 2 (Zero Hunger) and SDG 1 (Zero Poverty). A social enterprise that produces products from recycled materials not only creates economic value, but also directly contributes to SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action), and SDG 15 (Life on Land). Similarly, a smallholder cooperative that provides shared access to markets and resources not only improves the economic situation of its members but also addresses SDG 1 (Zero Poverty) and SDG 2 (Zero Hunger) by promoting sustainable agriculture and food security. In this sense, the SDGs provide a universal language and framework for SEOs, allowing them to articulate and measure their contributions in a way that is understandable to all stakeholders (Quiroz-Niño & Murga-Menoyo, 2017).

The link between mission and the SDGs is also strengthened by the way these organisations are governed. Democratic participation, a characteristic principle of cooperatives and associations, is in line with the spirit of

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2025 Volume 13 Number 2 (December)
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SDG 16 (Peace, justice and strong institutions), which promotes transparent and accountable institutions. By involving stakeholders – members, employees and communities – in decision-making, SEOs foster civic participation and strengthen social capital. This exemplary synergy between the internal functioning of the organisation and the global goals of governance and partnership is key to their effectiveness and sustainability in the long term (Quiroz-Niño & Murga-Menoyo, 2017; Feor et al., 2023).

In addition to direct contributions, SEOs also have an indirect impact on the SDGs by creating an enabling ecosystem (Figure 1). They often pioneer innovative approaches to solving social problems that can later be applied on a larger scale. For example, a successful social enterprise integrating people with disabilities into the labour market can serve as a model for public policies and employment programs (Berardi & Valentinetti, 2022). In this way, their contribution goes beyond immediate results and creates a ripple effect that supports progress on multiple SDGs simultaneously. This ability to innovate and replicate successful models is crucial in the context of challenges such as youth unemployment (SDG 8) or access to health care (SDG 3), where traditional approaches often fail (Kostadinova & Kunev, 2021; Berardi & Valentinetti, 2022).



Figure 1. SEOs ecosystem: *economic*, *social* and *environmental* linkages between the Sustainable Development Goals

Source: Author's development

The SDGs are therefore not just an external reporting standard, but are becoming an integral part of the strategic planning of SEOs. They allow organisations to structure their mission and measure their progress in a way that is aligned with global priorities. This link also provides significant benefits for the organisations themselves, including greater visibility, access to sustainability-focused funding, and stronger partnerships with the public and private sectors (de la Casa & Caballero, 2021). To exploit the full potential of this link, it is necessary to develop standardised and reliable impact measurement methods that capture both the quantitative and qualitative aspects of the contribution.

Despite the significant body of literature on both the social economy and the SDGs, there is a notable gap in the systematic and integrated study of the relationship between these two areas. The available publications often

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2025 Volume 13 Number 2 (December)
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address the topics in isolation or only in their particular aspects, without offering a comprehensive framework that connects the core principles of social economy organisations with the specific methods and tools for measuring their contribution to the SDGs. There is a lack of in-depth theoretical analysis that serves as a practical guide for organisations that seek to translate their social mission into measurable results aligned with the global SDG framework.

The main objective of this study is to create a bridge between the theory of the social economy and the practice of reporting on the contribution to the SDGs. Through an integrated theoretical analysis of the existing literature, the study aims to propose a comprehensive and structured model for understanding, measuring and reporting the impact of social economy organisations on the SDGs. The ultimate goal is to provide a clear roadmap for organisations to effectively communicate their value and demonstrate their role as key agents in achieving sustainable development.

Based on the stated goal and the identified gap, this study asks the following key questions:

- What is the *essential link between the principles and activities of social economy organisations and the specific SDGs*?
- What are *the main challenges in measuring the social and environmental impact* of these organisations, especially in the context of the SDGs?
- What are *the most appropriate qualitative and quantitative methods and tools* that social economy organisations can use to measure their contribution to the SDGs?
- *How can social economy organisations effectively report their contribution to the SDGs* to different stakeholders in order to increase their transparency and legitimacy?

3.2. Impact measurement as process (*Process*)

Measuring the impact of SEOs is a complex process that faces a number of significant challenges that go far beyond those inherent in financial reporting. The main obstacle is establishing causality. An organisation can contribute to positive change, but it is challenging to prove that its activities alone caused this change (Serje, 2017). For example, if a social enterprise trains unemployed people and they find jobs, this may be due to favourable economic conditions in the region, not just the training. The lack of appropriate control groups or baseline data makes it almost impossible to isolate the organisation's contribution from other external factors.

Another significant challenge is the lack of standardised metrics and indicators for measuring social and environmental impact. While in business, there are generally accepted standards such as International Accounting Standards (IAS) for financial reporting, in the area of impact, the diversity of methodologies (such as Social Return on Investment, Theory of change, *etc.*) often leads to incomparable results (Feor et al., 2023). An organisation may use its system of indicators, which would make it difficult to compare its contribution with that of other organisations. This fragmentation of approaches complicates the aggregation of data at the sectoral or national level. It makes it impossible to create a single, reliable picture of the overall contribution of the social economy.

The high cost of measurement also represents a serious barrier, especially for small and start-up SEOs, which often have limited resources. Effective impact measurement requires significant investments in human capital (experts), technology (data analysis software) and time (EC, 2013; Pavlov & Ruskova, 2023). Collecting qualitative data, conducting interviews, surveys and producing in-depth reports can take months and be financially prohibitive. As a result, many organisations limit themselves to reporting only key outcomes, which fails to capture their actual contribution and impact.

Relatedly, collecting data from different stakeholders is a complex and time-consuming process. An organisation's impact is often felt by multiple groups – customers, employees, volunteers, local communities, suppliers and public institutions. Each group may have a different perspective on the change that has occurred, and collecting information from all of them requires a variety of methods and approaches (Ebrahim & Rangan, 2014). Ensuring the accuracy and reliability of this data, especially when it is subjective or qualitative, is another

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
https://doi.org/10.9770/j2805824856

serious challenge. In addition, there are ethical issues related to protecting personal data and ensuring the confidentiality of research participants.

These challenges are particularly pronounced in the context of the relationship between the social economy and the SDGs. Although the SDGs provide a clear framework, the lack of a unified methodology for mapping organisations' activities to specific SDG indicators remains a problem (Quiroz-Niño & Murga-Menoyo, 2017). For example, how does one measure an organisation's contribution to SDG 10 (Reduced Inequalities) or SDG 16 (Peace, Justice and Strong Institutions) in a standardised and universal way? This necessitates the development of common frameworks that serve as a roadmap for all stakeholders and allow for more consistent and reliable reporting of the impact of the social economy (de la Casa & Caballero, 2021).

At the heart of the measurement process is the development of a Theory of Change. This is a fundamental planning and evaluation tool that describes the causal pathways through which an organisation's activities lead to desired long-term outcomes and impacts. A Theory of change begins by defining an end goal (e.g. poverty reduction). Then it works backwards to identify all the necessary inputs, outputs and outcomes that need to occur in order to achieve that goal. It provides a logical framework that links the day-to-day activities of the organisation (e.g. delivering training) to its strategic impact objectives (e.g. increased employment) (UNDP, n.d.; Le Grange & Maas, 2023).

Linking the Theory of Change to the SDGs is a key aspect for SEOs. By mapping their activities (Table 2) and expected outcomes to specific SDG targets and indicators, organisations not only demonstrate their contribution to the global goals but also gain access to a universal set of indicators that they can use for measurement. For example, a social enterprise whose mission is to provide access to clean water could link its indicators directly to SDG 6 (Clean water and sanitation) and its sub-targets. This approach ensures clarity and comparability of data, while helping the organisation define precisely what it is trying to achieve and how it will measure it (UNDP, n.d.; EC, 2013).

Table 2. Stages and activities in the results measurement process

Stage	Description	Key questions
Theory of Change & SDGs	Develop a logical framework that shows how activities lead to impact.	What inputs (resources) does the organisation have? What are its activities? What outputs and outcomes does it expect? What is its long-term impact? How does its mission connect to specific SDGs?
1. Planning	Define the objectives, scope, and resources for the measurement process.	What does the organisation want to measure and why? Who is the measurement intended for (donors, management, customers)? What resources (financial, human) are needed?
2. Identifying stakeholders	Identifying all groups and individuals who are affected by the organisation's activities.	Who are the organisation's key stakeholders? What is their role in the measurement process? What is important to them?
3. Selecting indicators	Defining key indicators to track progress.	What are the most appropriate quantitative and qualitative indicators? How can the indicators be linked to the SDGs? How will both outputs and outcomes be measured?
4. Data Collection	Systematic collection of information from various sources.	Who will collect the data and how? What methods will be used (surveys, interviews, observation)? From which stakeholders will data be collected?
5. Data Analysis	Summary and Interpretation of the Information Collected.	What does the data show? Is there a match between outputs, results, and impact? Does the organisation take external factors into account?
6. Validate the results	Check the accuracy and reliability of the conclusions.	How did the organisation confirm the reliability of the results? How will it share the results with stakeholders? How will it use the results to improve its operations?

Source: Author's development

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2025 Volume 13 Number 2 (December)
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3.3. Impact measurement approaches (*Methods*)

Measuring the impact of SEOs requires the application of different methods that can capture both the measurable and intangible aspects of change (Sabauri & Kvatashidze, 2023; Jamburia & Courrent, 2024). There is no universal approach, but rather a combination of qualitative and quantitative methods that provides the most complete picture of the value created. Despite the lack of a single, universal standard, a number of tools and frameworks for measuring social and environmental impact have been developed in recent years that can be adapted by SEOs for SDG reporting. These tools offer structured approaches to defining, tracking and assessing value created, seeking to overcome the challenges associated with data collection and analysis (Feor et al., 2023).

Quantitative methods
Quantitative methods focus on measurable data and numerical indicators. Using specific indicators linked to the SDGs is a more practical and direct quantitative approach. For example, an organisation working on social inclusion might measure the number of jobs created for vulnerable groups (linked to SDGs 8 and 10). In contrast, an environmental social enterprise might track the tons of waste recycled (related to SDGs 12) or the number of people trained in separate collection (linked to SDGs 4 and 12) (Quiroz-Niño & Murga-Menoyo, 2017; Reinecke & Wrona, 2024). These indicators are easy to track and provide concrete data on the outcomes and results achieved. Surveys and interviews conducted among target groups are also an essential quantitative tool for collecting data showing changes in people's knowledge, skills or behaviour.

Another quantitative method is *Cost-Benefit Analysis* (CBA), which compares the total costs of an initiative with the total benefits, both expressed in monetary terms. This approach helps in decision-making, but also faces difficulties in valuing social and environmental benefits that cannot be easily monetised (Goel & Sharma, 2021). The specificity of this method is that, although it is a highly quantitative method that seeks to convert all variables into a monetary value, it is not purely quantitative to the same extent as impact assessment methods that rely exclusively on numbers, without converting non-monetary values into financial values. The main challenge and reason for not being considered "purely" quantitative is that CBA must attribute an economic value to intangible benefits. For example, how much is a saved human life, reduced stress levels or increased community self-esteem worth? This assessment is subjective and can vary significantly, which introduces a qualitative element into the process.

Qualitative methods
Qualitative methods are essential for understanding the depth and complexity of change that cannot be captured by numbers alone. Interviews conducted with employees, customers, partners, and other stakeholders provide a wealth of information about their experiences and experiences of change (Ebrahim & Rangan, 2014). They allow the researcher to understand "how" and "why" a given impact occurred, capturing nuances that quantitative data misses. Focus groups also provide a platform for gathering opinions and perspectives from multiple participants simultaneously, revealing common themes and collective attitudes. Case studies are another powerful qualitative method that involves in-depth analysis of a specific organisation, project, or situation. They provide a detailed narrative of the change process, showing challenges, successes, and key lessons learned. Analysing narratives or "change stories" allows target groups to tell their own stories about how their lives have changed as a result of the organisation's activities. These stories can be a potent tool for communicating impact to a broad audience and donors.

Hybrid/Mixed methods
The most effective approach in modern practice is the use of hybrid or mixed methods, which combine quantitative and qualitative approaches to provide a more complete and reliable picture of impact, by combining numerical data on the results achieved (e.g., number of people employed) with qualitative stories and testimonies (interviews with these people), a much deeper understanding of the net change is achieved (EC, 2013). Quantitative data can show the scale of the impact, while qualitative methods reveal its depth and meaning for individuals. This synergistic approach is critical in the context of the social economy, where the mission is linked to complex social processes. It allows organisations not only to prove their contribution with numbers but also to tell the impactful story behind them, which is crucial for the engagement of all stakeholders.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
https://doi.org/10.9770/j2805824856

One of the most popular and widely adopted sets of indicators is *IRIS+* (Impact Reporting and Investment Standards), developed by the Global Impact Investment Network (GIIN). IRIS+ provides a standardised catalogue of indicators that cover different sectors and types of impact, including social, environmental, and financial (IRIS, n.d.). The platform is handy because it offers investors and organisations a common language for describing impact. It categorises indicators by major sectors (such as agriculture, health, and education) and links each of them to relevant SDG targets and indicators. This makes IRIS+ an excellent tool for organisations that want to link their contributions to global goals reliably and comparably. For example, an organisation in the field of education can easily identify and use indicators related to the number of students trained or the percentage of graduates that are found in the IRIS+ catalogue and link them directly to SDG 4 (Quality Education).

Another vital framework is that of *Social Value International*, which focuses on *Social Return on Investment* (SROI) – an impact evaluation methodology that seeks to assess social, environmental and economic outcomes by giving them a monetary value. What is specific about SROI is that although the final result is quantitative (a monetary ratio that shows how much social value is created for each unit invested) and, for this reason, can also be referred to as quantitative methods, the calculation process is based on qualitative data. To determine the value, stories and testimonies are collected from stakeholders who describe the changes in their lives. These changes are then assigned a monetary value. Therefore, SROI combines in-depth qualitative research with quantitative calculation, making it a hybrid method. Although SROI offers a holistic view, it has been criticised (as well as Cost-Benefit Analysis) for being subjective in assessing intangible benefits. At the same time, it can be expensive and time-consuming to implement (Social Value International, n.d.; Corvo et al., 2022).

Although SROI is more complex to implement than IRIS+, its focus on the story of change and stakeholder engagement makes it extremely valuable. It forces organisations to ask themselves key questions: What change has occurred? Who has experienced it? What is the value of this change? The SROI framework can be effectively adapted for SDG reporting, with the monetary value of impact being presented in the context of the specific SDGs it contributes to. For example, an SROI assessment of a social housing project could show the monetised value of the improved health (SDG 3) and reduced crime (SDG 16) created by the project.

In addition to these two main frameworks, other tools focus on more specific aspects. The *B Impact Assessment*, for example, is an online assessment tool that measures a company's overall impact on its employees, community, environment, and customers. Although designed for companies certified as "B Corps," it offers a detailed set of questions and indicators that any social economy organisation can use to self-assess and identify areas for improvement in the context of the SDGs (B Lab, n.d.). Similarly, the *Global Reporting Initiative* (GRI) provides widely recognised sustainability reporting standards that include both financial and non-financial indicators and can be used by large social enterprises for structured reporting (GRI, n.d.).

All of these tools and frameworks have a common goal: to transform the abstract concept of "*impact*" into measurable and manageable data. Their strength lies in their ability to provide a structure and methodology that helps organisations move from simply measuring outputs to a deeper understanding of results and long-term impact. Their adaptation for SDG reporting purposes is achieved by mapping their specific indicators to official UN indicators, ensuring that the information reported is not only comparable but also relevant to the global sustainable development agenda.

3.4. Approaches to reporting on SDG impact (*Reporting*)

Impact reporting is another critical process for SEOs that transforms their internal activities into tangible and communicable social value. An impact report is not just a formal obligation, but a strategic tool that increases the transparency and accountability of the organisation by demonstrating its contribution to positive change in society and the environment (de la Casa & Caballero, 2021). This transparency is essential for building trust and legitimacy with various stakeholders. Effective reporting allows organisations to demonstrate how their efforts are aligned with the global priorities of the SDGs, which can attract funding, investment and new partnerships, especially from sustainability-oriented funds and donors. Furthermore, the reporting process

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
https://doi.org/10.9770/j2805824856

promotes learning and improvement within the organisation itself, helping management identify its strengths and weaknesses and optimise its strategies for future impact.

The impact report is addressed to a wide range of stakeholders, each with their own specific information needs (Ebrahim & Rangan, 2014), including:

- *Investors and donors* seek evidence that their funds are being used effectively to achieve the planned social and environmental outcomes. They need reliable impact data to justify their investment.
- *Public institutions* (governments, municipalities) use these reports to assess the contribution of the social economy to the implementation of national and regional development plans and to guide public support policies.
- *Customers and consumers* are increasingly interested in the ethical side of the products and services they consume, and reports help them make informed choices.
- *Employees and volunteers* are motivated by a clear vision of the positive change they are helping to create.
- *The community* significantly needs information about how organisations contribute to improving the quality of life and solving local problems.

An impact report is not just a report, but a comprehensive narrative of the change an organisation is making. To be scientifically robust and impactful, it must interweave quantitative data with qualitative narratives, creating a complete and compelling picture. The report begins with a clear definition of the organisation's mission and its relationship to the United Nations SDGs. That places its work in a broader global context, showing how the specific work contributes to the achievement of universal goals. It then specifies the selected SDGs and their sub-goals to which the contribution is directed, often supported by visual elements such as icons of the goals themselves, which facilitates perception.

To ensure the legitimacy of the data, the report should include a detailed methodology for measuring impact. The approaches, tools and indicators used, such as SROI, the IRIS+ framework or the Theory of Change, should be described. This section demonstrates the scientific rigour and seriousness with which the evaluation of results is approached. Key indicators and results achieved should be presented through a combination of quantitative and qualitative data. Quantitative results, such as the number of people trained or the amount of waste recycled, should be linked to specific SDG indicators. This data is complemented by qualitative information collected through surveys and interviews, which adds depth and a human dimension. As Feor *et al*. (2023) point out, this synthesis of data is essential for a complete evaluation. To illustrate the impact at the human level, case studies are included that tell the story of specific people whose lives have been positively affected by the organisation's activities, such as finding decent work.

To demonstrate maturity and commitment to continuous improvement, the report should be transparent about the challenges and lessons learned along the way to achieving impact. According to the European Commission, honesty about the difficulties encountered in the measurement process increases trust. The final section outlines plans, presenting strategic directions and objectives for the next period. This provides a vision of how the organisation will continue to increase its impact and contribute even more effectively to the achievement of the SDGs (EC, 2013; European Commission. Internal Market, Industry, Entrepreneurship and SMEs, n.d.).

Impact reports can take different forms depending on the audience and the resources of the organisation.

- Annual activity reports or specialised impact reports provide the most detailed information and are suitable for donors and partners.
- Website sections or infographics are excellent for a broad audience and can be updated regularly.
- Integrated reports combine financial and non-financial results in a single document, showing how the two sides of the operation are interconnected and mutually reinforcing. This format is gaining popularity because it provides a holistic picture of the value created by the organisation (GRI, n.d.).

Finally, for a report to be effective, it must explicitly demonstrate the link to the SDG framework. That is achieved by using the language and visual elements of the SDGs. Including the icons of the relevant SDGs next

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
https://doi.org/10.9770/j2805824856

to each section of the report related to them makes it easier to identify the contribution quickly. For example, a section on sustainable production initiatives could be labelled with the icon of SDG 12 (*Responsible Consumption and Production*). Using the official SDG targets and indicators as a starting point for measurement and reporting also contributes to the legitimacy of the report. It makes it comparable with data at a global level. This approach allows SEOs to position themselves not just as local players, but as international partners in achieving a more sustainable and equitable future for all.

3.5. Impact measurement and reporting model

Considering the points presented thus far allows the construction and formulation of a conceptual framework for measurement and reporting, including four main steps: *Theory*, *Process*, *Method*, and *Report*. The framework is designed to facilitate SEOs in the step-by-step process of measuring and reporting their activities directly related to the SDGs. *The Impact Measurement and Reporting Model* (Figure 2) is structured as an organised mind map that demonstrates the logical and cyclical process from the organisation's mission to reporting its contribution. This model, although presented in layers, actually represents a single whole, where each component is closely related to the others, ensuring comprehensive and transparent reporting.

At the very centre of the model is the heart of each organisation — its mission. It serves as a driving force and determines the direction of all activities. From it, two key elements emerge, which are in constant interrelation: A *Theory of Change* and the *Global SDGs*. The Theory of Change is a detailed roadmap that shows the logical sequence from inputs and activities to results and long-term impact. It is not just a list of steps, but a strategic framework that explains how and why specific activities will lead to the desired change. It is this theory (The *Theory* step) that connects the mission to the entire measurement and reporting process.

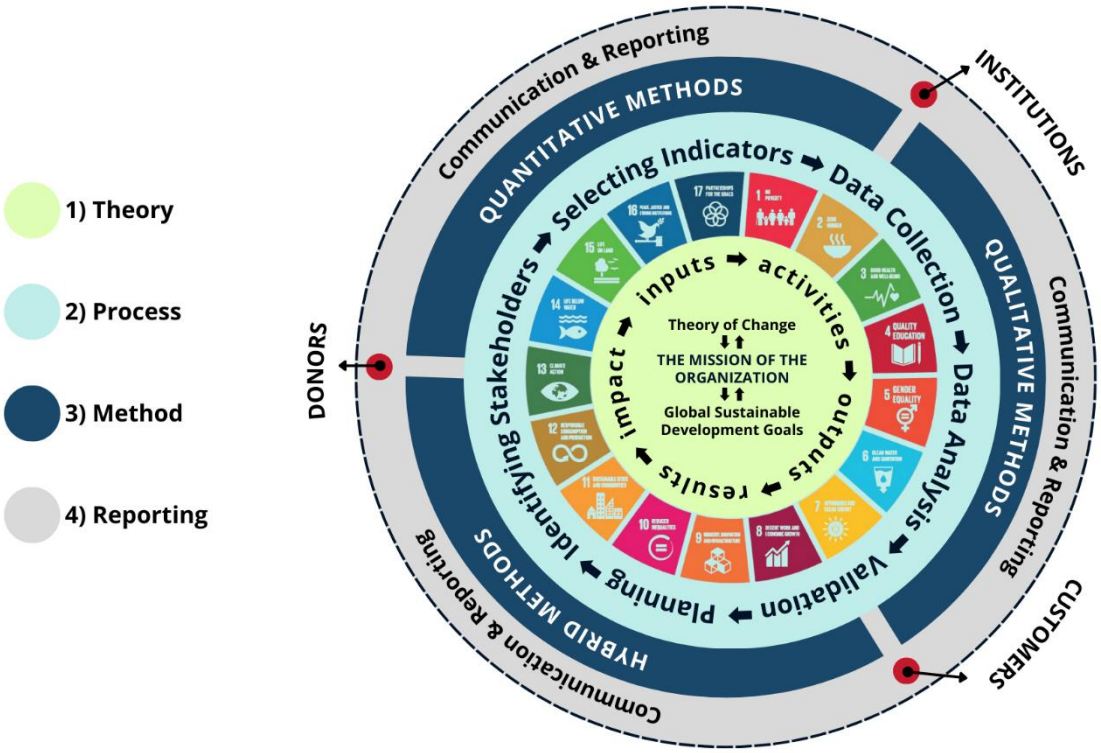


Figure 2. A conceptual model for measuring and reporting the impact of SEOs on achieving the global SDGs

Source: Author's development

In close proximity to the Theory of Change are the icons of the SDGs, to which the organisation should directly or indirectly contribute. That emphasises not only the local but also the global significance of the activity,

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
https://doi.org/10.9770/j2805824856

showing that the organisation's efforts are part of a broader, universal aspiration for sustainability and development. It is important to note that each SDG requires a specific resource and set of activities; therefore, each SDG chosen by the SEOs should "*walk*" its steps through the proposed model. That also imposes another principle on these types of organisations: to define their SDGs and limit them to 1 or 2 to accurately report the direct and indirect results. That does not mean that connections with and impact on the other SDGs should not be sought, but that when documenting the results of their activities, SEOs should focus on those SDGs that are most closely related to the mission, vision, goals, and principles of the organisation.

The first concentric circle around the core of the model describes the measurement cycle itself (*Process*). It is sequential and cyclical, moving clockwise, symbolising continuous learning and improvement. The process begins with Impact Planning, where the objectives and scope of the measurement are defined. Stakeholder Identification follows this, as their needs and expectations are essential for determining exactly what needs to be measured.

Once stakeholders have been identified, the next step is to select indicators that will be used to measure progress. These indicators should be specific, measurable, achievable, relevant and time-bound (SMART). The next stage is Data Collection, which is critical to providing accurate and reliable information. The collected data is then subjected to Analysis to draw meaningful conclusions and understand the impact achieved. Before being used for reporting, the data goes through a Validation process that ensures its credibility. This cycle does not end with the report, but goes back to the planning stage, with lessons learned from the previous cycle being used to improve the next.

The second circle around the measurement cycle presents the methods and tools (*Method*) that are used at each stage. It is divided into three main sectors, which show the wealth of approaches with which impact can be measured. Quantitative methods focus on measuring impact through numerical data. Examples of such methods are SROI analysis and Cost-Benefit Analysis. These tools help to calculate the monetary value of social impact by providing a clear, measurable framework.

In contrast, qualitative methods aim to capture the human story behind the numbers. They include tools such as in-depth interviews, focus groups and case studies. They collect stories and experiences that add depth and context to quantitative data, revealing the "*why*" and "*how*" change is happening. While each approach has its advantages, the most effective is the hybrid approach that combines quantitative and qualitative methods. This combination allows for a complete and balanced picture of the impact, measuring both its scope and depth.

The outermost layer of the model is dedicated to communication and reporting (*Reporting*) – the final point of the entire process. This stage is essential because it is through it that the results are presented to stakeholders and the loop is closed. The key elements of the report include not only dry data and indicators, but also narrative parts that make the information understandable and engaging. These include a clear presentation of the mission, indicators achieved, change stories that illustrate impact, as well as lessons learned and future improvement plans.

Reports can be presented in a variety of formats, depending on the audience. Traditional annual reports, dynamic and interactive websites, or comprehensive integrated reports that combine financial and social indicators are just some of the possible ways to present information. From this outer layer, reporting is directed to various stakeholders, such as donors, public institutions, and customers, demonstrating that the report is personalised and designed to meet the needs of each specific group (de la Casa & Caballero, 2021). Ultimately, this process results in transparency and accountability, which are the foundation of the trust and sustainability of any organisation.

Challenges and opportunities in measuring and reporting in the context of the SDGs

The preceding analysis indicates that measuring and reporting impact on the SDGs is both a challenge and an opportunity for SEOs. Despite the growing interest and importance, this process faces a number of obstacles related to resources, capacity and methodology. Above all, high costs and limited resources are a serious barrier, especially for small and newly established organisations. A thorough impact measurement requires not only

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
https://doi.org/10.9770/j2805824856

financial resources, but also significant human resources and time. Organisations are often forced to choose between investing in their core business and investing in impact assessment, which can lead to neglecting the latter (Kostadinova & Kunev, 2021; Le Grange & Maas, 2023).

Related to this, the need for specialised capacity (knowledge and skills) is another key challenge. Measuring impact requires specific expertise in social sciences, statistics and data analysis, which are often lacking in small organisations (EC, 2013; Pavlov & Ruskova, 2023). Hiring external consultants can be a solution, but again, this is associated with high costs. That creates a vicious circle in which the lack of resources hinders the building of capacity, which in turn limits the possibilities for effective measurement and reporting.

The lack of commonly accepted and standardised standards and metrics has been a long-standing problem in the sector (Feor *et al.*, 2023; Reinecke & Wrona, 2024). Although tools such as IRIS+ and SROI are gaining popularity, they are not yet universally accepted and applied, making it extremely difficult to compare results across organisations or sectors (Corvo et al., 2022). This fragmentation of approaches slows down the development of a comprehensive picture of the social economy's contribution to the SDGs at national and global levels. However, progress in this direction is visible, as more and more stakeholders (investors, governments) demand reporting according to standardised frameworks. Another important aspect is the risk of "*social washing*" or "*greenwashing*". This is a phenomenon in which organisations present an apparent, rather than real, change in order to improve their image in the public eye and attract funding (Ebrahim & Rangan, 2014; Lanzalonga et al., 2023). To avoid this, it is necessary to focus on transparency and independent validation of results. Reports should include not only positive outcomes, but also challenges and lessons learned in the process. Additionally, external auditing of the data by independent organisations can ensure its credibility and enhance stakeholder trust.

Alongside the challenges, there are also significant opportunities for collaboration and innovation. SEOs can work together to share experiences, good practices and develop standardised measurement processes (Quiroz-Niño & Murga-Menoyo, 2017). Creating networks and platforms for data sharing can reduce costs for each organisation and facilitate the aggregation of results (Ayob et al., 2022; Kwon et al., 2024; Mohamed et al., 2024; de Bell & Bakker, 2025).

This collective approach is particularly important for achieving SDG 17 (Partnership for the Goals) as it demonstrates that the social economy acts as a single, coordinated sector. The role of technology and digitalisation presents a key opportunity to address the challenges. The development of software platforms and mobile applications facilitates the collection, analysis and reporting of impact data (Social Value International, n.d.). Automated tools can reduce the time and costs required for the process, while improving the accuracy and reliability of the information. The use of Big Data and artificial intelligence can also contribute to deeper impact analysis by uncovering hidden causal relationships and trends (Berardi & Valentinetti, 2022; Kirova & Boneva, 2024).

The ability to report digitally in real time will allow organisations to track their progress continuously, rather than just once a year. This dynamic transparency can build stronger relationships with donors and investors by providing them with up-to-date information on the progress of their investments. Digital platforms can also facilitate the sharing of stories of change through video, photos, and other multimedia formats, making reporting more engaging and impactful (Berardi & Valentinetti, 2022).

Ultimately, overcoming challenges requires systemic change and collective efforts. Governments, funders, and SEOs must work together to create an enabling environment that encourages and supports impact measurement. This includes providing financial support for capacity, developing standard guidelines and reporting platforms, and promoting a culture of transparency and accountability. In this way, the social economy will be able not only to achieve, but also to prove its significant contribution to achieving the SDGs.

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2025 Volume 13 Number 2 (December)
https://doi.org/10.9770/j2805824856

4. Case study: Conceptual framework for measurement and reporting (*Theory, Process, Method, Report*) in the context of Grameen Bank

Theory

One of the most well-known and successful examples of a social economy organisation that has measured and reported its impact on a large scale is Grameen Bank. Founded by Nobel Peace Prize winner Muhammad Yunus in Bangladesh, Grameen Bank pioneered the concept of microcredit – providing small loans to people living in poverty without requiring collateral (Yunus, 2008). The bank's mission directly addresses SDG 1 (No Poverty) by providing economic opportunities to rural women. Although founded long before the adoption of the SDGs, Grameen Bank's work serves as a classic example of how a social economy organisation can achieve measurable and long-term impact that is fully aligned with the global goals.

Although it was established before the SDGs, Grameen Bank's organisational model is fully aligned with them. The bank's reports now explicitly link to the SDGs, using their icons and language to demonstrate its contribution more clearly. This approach not only facilitates communication with international partners and donors but also serves as a model for how organisations can transform their mission into measurable contributions to the global goals (Quiroz-Niño & Murga-Menoyo, 2017; Grameen Bank, n.d.).

Grameen Bank's impact is directly linked to multiple SDGs (Grameen Bank, n.d.), making it an excellent example of effective reporting:

- SDG 1 (No Poverty): The bank's primary contribution is through access to capital, which enables people to start or expand their businesses and lift themselves out of poverty.
- SDG 5 (Gender Equality): By focusing on women as its primary clients (over 97%), Grameen Bank promotes their economic empowerment and enhances their social and political role in communities.
- SDG 8 (Decent Work and Economic Growth): Microcredit supports the creation of self-employment and stimulates the local economy.
- SDG 4 (Quality Education): Higher incomes allow families to invest in their children's education.
- SDG 3 (Good Health and Well-being): Improved financial status often leads to better access to health services and better nutrition.

Process

The Grameen Bank experience shows that success in measuring and reporting impact is achieved through a combination of financial and social discipline. The bank demonstrates that it is possible to achieve economic success (high repayment rates) without compromising the social mission. This integrated approach is key to the sustainability of SEOs and their ability to contribute effectively to the SDGs.

Table 3. Stages and activities in the results measurement process

Stage	Key questions	Key questions
Theory of Change & SDGs	What inputs (resources) does the organisation have? What are its activities? What outputs and outcomes does it expect? What is its long-term impact? How does its mission connect to specific SDGs?	*Inputs*: Loan capital, staff, community trust. *Activities*: Providing microcredit to poor people (especially women) without collateral, training borrowers. *Outputs*: Number of loans disbursed, loan size, number of members (borrowers). *Long-term impact*: Poverty reduction, economic and social empowerment of women, improvement of living standards. *Linkage to SDGs*: Directly linked to SDG 1 (No poverty) and SDG 5 (Gender equality).
1. Planning	What does the organisation want to measure and why? Who is the measurement intended for (donors, management, customers)? What resources (financial, human) are needed?	The bank wants to measure its effectiveness in fighting poverty by tracking the success of its borrowers. The measurement is for the bank's management, donors, and the public. Teams of loan officers and data collection systems are needed.
2. Identifying stakeholders	Who are the organisation's key stakeholders? What is their role in the measurement process? What is important to them?	Borrowers (members) are the primary stakeholders. Their role is to provide information about their economic situation and participate in the process. They need to see that the loan helps them and that their lives improve. Other stakeholders are employees and donors.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
https://doi.org/10.9770/j2805824856

3. Selecting indicators	What are the most appropriate quantitative and qualitative indicators? How can the indicators be linked to the SDGs? How will both outputs and outcomes be measured?	*Quantitative indicators*: Loan repayment rate, number of women borrowers, and increase in family income. *Qualitative indicators*: Stories of women's empowerment, improved social status. *Link to SDGs*: Income growth and access to finance are linked to SDG 1 and measured through the collection of repayment data and periodic household surveys.
4. Data Collection	Who will collect the data and how? What methods will be used (surveys, interviews, observation)? From which stakeholders will data be collected?	The bank's loan officers collect data during their weekly visits to the villages. Methods include direct interviews, observation, and repayment tracking. Data is collected primarily from borrowers (bank members).
5. Data Analysis	What does the data show? Is there a match between outputs, results, and impact? Does the organisation take external factors into account?	The data shows a high loan repayment rate and an increase in members' income. These results are consistent with the goal of poverty reduction. The bank takes into account external factors such as natural disasters or economic crises, but the basic model remains sustainable.
6. Validate the results	How did the organisation confirm the reliability of the results? How will it share the results with stakeholders? How will it use the results to improve its operations?	Reliability is confirmed through regular audits and on-site inspections. The results are shared through annual reports, publications and stakeholder meetings. The results are used to improve credit products, expand into new areas and offer new services such as savings accounts and insurance.

Source: Author's development

Method

Grameen Bank uses a hybrid approach to measuring impact, combining both quantitative and qualitative indicators. Quantitatively, the bank tracks key financial and social indicators, such as the number of loans disbursed, the repayment rate, the number of clients served, and the growth in borrowers' income (Grameen Bank, 2023). This data is easy to collect and provides a clear picture of financial success and operational efficiency. On the other hand, Grameen Bank focuses on qualitative impact, examining changes in the quality of life of its clients. Regular surveys, interviews, and focus groups are conducted to understand deeper aspects such as the rise in the social status of women, their role in household decision-making, access to education for their children, and improved health conditions (Khandker, 2005).

Reporting

Grameen Bank and its subsidiaries publish annual activity reports that include both financial statements and detailed sections on social impact. These reports are available on their website and provide information on the results achieved in the context of the bank's original mission. Additionally, Grameen Trust, a subsidiary of Grameen Bank that disseminates the model, publishes separate reports showing the impact of microcredit on different communities worldwide (Grameen Bank, 2023). This practice provides a high degree of transparency and allows donors, governments and researchers to assess the effectiveness of the model. The bank also actively collaborates with academic institutions to conduct independent studies that confirm its impact.

The Grameen Bank case study is an example of successful and effective measurement and reporting of an organisation's impact directly linked to the SDGs. The bank's model is clearly focused on SDG 1 (No Poverty), but also on SDG 5 (Gender Equality), using a system of quantitative and qualitative indicators to demonstrate progress. Accordingly, rather than focusing solely on financial indicators such as profit, Grameen Bank emphasises SROI, measuring its success through repayment rates, increased household incomes, and women's social empowerment. This approach provides reliable and verifiable information that demonstrates how microfinance is an effective tool for achieving specific SDGs.

Reporting on results is done through public reports that communicate this progress to stakeholders. By applying the *Theory of Change* as a framework, the organisation is able to explain in a transparent and informative way how its *activities* (lending) lead to immediate *outcomes* (increased income) and ultimately to the long-term *impact* of poverty reduction (SDG 1). This methodology demonstrates its accountability and transparency by transforming raw data into a meaningful story of social change that is in line with global efforts for sustainable development. At the same time, the presented *Conceptual Framework for Measurement and Reporting (Theory, Process, Method, Report)* in the context of Grameen Bank (Figure 3) allows other organisations to adapt this

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
https://doi.org/10.9770/j2805824856

methodology to their own goals and activities and to report on their results in a practical, transparent and reliable manner.

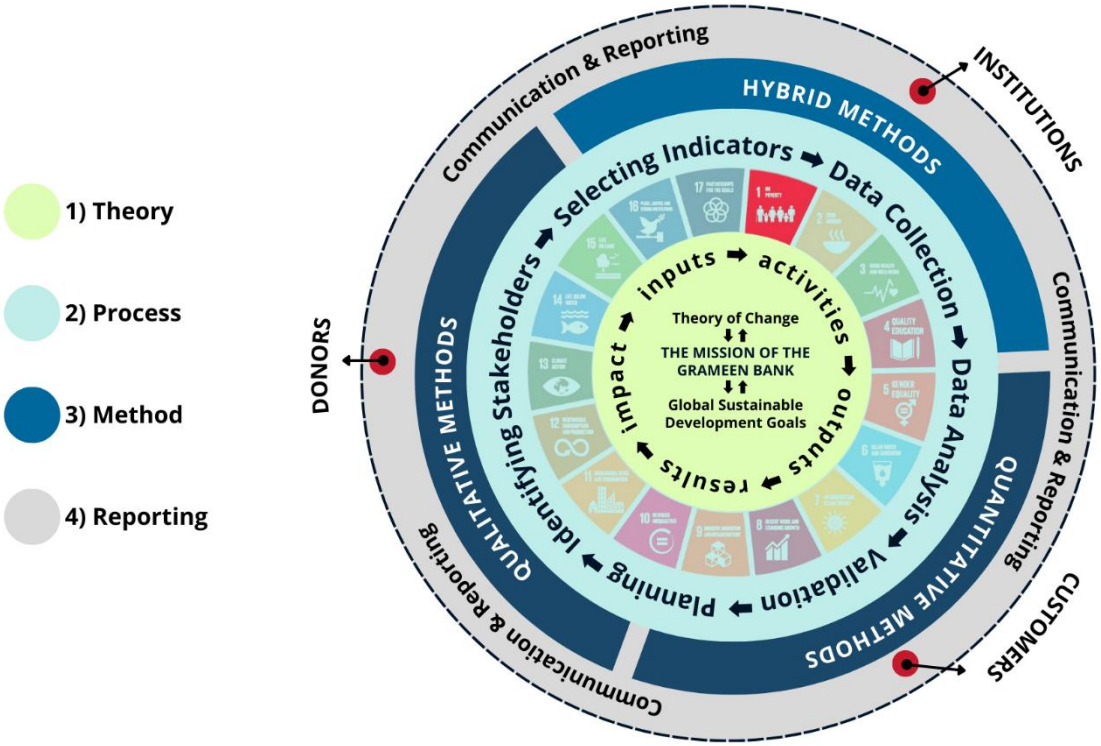


Figure 3. Conceptual Framework for Measurement and Reporting (*Theory, Process, Method, Report*) in the context of Grameen Bank

Source: Author's development

In summary, the presented case study and the shared experience of Grameen Bank offer important lessons for other organisations that want to measure and report their impact. One of the main challenges is avoiding "*social washing*" by ensuring that the change reported is real. Grameen Bank overcomes this by combining quantitative and qualitative data, as well as independent evaluations that validate the results. Another lesson is that measuring impact is not a one-time process, but a continuous cycle of data collection, analysis, and strategy adjustment. The bank is constantly adapting its model to meet the changing needs of its clients.

Establishing a direct causal link between microcredit and outcomes remains a challenge. Although there is a correlation between microcredit provision and improved lives, it is difficult to prove that this is due solely to the bank and not to other factors such as overall economic development. Grameen Bank addresses this by collecting data over a long period and through in-depth qualitative research that reveals personal stories of change.

5. Contribution and limitations of the study

Implications

The knowledge presented in the paper is intended for a wide range of stakeholders. First of all, it is aimed at practitioners from SEOs who are looking for guidance on how to measure and report their contribution to the SDGs effectively and reliably. Furthermore, it is helpful for public institutions and donors who need a framework for assessing the impact of the initiatives they support. Last but not least, the manuscript serves as a resource for researchers and students studying the social economy, sustainable development and impact measurement.

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2025 Volume 13 Number 2 (December)
https://doi.org/10.9770/j2805824856

The theoretical contribution of the manuscript consists in systematising existing concepts and frameworks into a coherent model that links the mission of the social economy to the global goals: *1) Theory* (impact and mission); *2) Process* (impact measurement cycle); *3) Method* (measurement methods and tools applied); *4) Reporting* (impact report structure including mission, indicators, change stories and plans). This model, on the one hand, provides *a new, integrated framework for impact analysis* that goes beyond traditional approaches, and on the other hand, represents *an ideal, consistent path that an organisation can follow to measure and report its contribution*. The applied contribution lies in providing practical guidance and concrete tools that can be adapted and used by organisations in their daily activities to become more transparent and effective in their impact.

Study limitations

Despite the in-depth analysis, the study has its limitations. The main one is that it is theoretical and qualitative, and does not include new empirical research. The data analysed are secondary, based on existing reports and scientific publications. Therefore, the conclusions are based on synthesis, not on primary field data. Another limitation is that the manuscript proposes a general model that may not be applicable in every specific case. Its limitations arise from the great diversity in the social economy:

- *Different types of organisations*: A small voluntary organisation with a limited budget cannot apply the same in-depth methodology as a significant social enterprise with an impact analysis team;
- *Sector specificities*: The impact of an agricultural cooperative (related to SDGs 2 and 12) is measured with very different indicators than the impact of a foundation supporting education (SDG 4);
- *Resources and capacity*: The model assumes the presence of specific resources and knowledge that many organisations do not have.

In this sense, the paper proposes the *ideal model*. Still recognises that *organisations must adapt it to their specific needs, resources, and context*, using tools and approaches appropriate to their case.

Conclusions

This study systematises and justifies the key role of SEOs as key partners in achieving the Global SDGs. The introduction clearly defines the SDGs as a universal framework for action and positions the social economy – with its core principles of democratic governance and social mission – as a natural and powerful tool for implementing this agenda. Organisations such as cooperatives, social enterprises and foundations do not simply generate economic activity, but create profound social and environmental value that is directly aligned with the spirit of the 2030 Agenda.

The distinction between output, outcome and impact is fundamental to understanding the contribution of the social economy. While outputs are easily measurable products and services, the real value lies in the long-term impact, which is often complex, qualitative and difficult to quantify. This impact is embedded in the very mission of these organisations, creating an inextricable link to the SDGs. For example, an organisation working for social inclusion directly contributes to SDG 10 (Reduce inequalities), regardless of the outcome of its activities.

Despite this natural synergy, measuring and reporting impact comes with significant challenges. These include the difficulty of establishing causal relationships, the lack of standardised metrics, and the need for specialised capacity and resources. These barriers often prevent organisations, especially small ones, from demonstrating their full contribution. This issue is critical because there is a risk of "*social washing*" – presenting a false sense of change instead of real, long-term impact.

To overcome these challenges, various methods and tools have been developed. Approaches such as SROI and the use of specific indicators linked to the SDGs provide numerical evidence. At the same time, qualitative methods such as interviews and change stories offer depth and a human dimension to impact. The most effective approach appears to be a hybrid approach, which combines the two categories to provide a comprehensive and reliable picture.

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2025 Volume 13 Number 2 (December)
https://doi.org/10.9770/j2805824856

As a main contribution, this study proposes a conceptual model for measuring and reporting the impact of SEOs on the achievement of the SDGs, which is cyclical and begins with precise planning and defining a Theory of Change that links the organisation's activities to the desired impact and the relevant SDGs. This process is essential for creating a logical framework to guide the selection of appropriate indicators and data collection methods. Reporting of these results is addressed to a wide range of stakeholders, including donors, governments and clients, with the aim of increasing transparency and building trust.

In conclusion, the social economy has the inherent potential to be a major driver of sustainable development. To fully realise this potential, the sector needs to invest in building capacity to measure impact and foster collaboration. The innovative aspect of this study is that it provides a single and coherent theoretical framework that offers a comprehensive and integrated approach to impact measurement. To expand this contribution, future research should focus on empirically testing the proposed model in real-world conditions, as well as on developing sector-specific indicators.

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IMPACT OF STRATEGIC CORPORATE INVESTMENTS ON COMPANIES' PERFORMANCE: A CASE OF SLOVENIA

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Abstract. In this article, the author investigates the role of strategic corporate investments, positioning them as the primary mechanism through which firms create shareholder value and enhance owner wealth. The study focuses on their influence on corporate growth, company valuation, productivity, and overall business performance. Its central objective is to present and empirically validate three research hypotheses related to these relationships.The theoretical contribution of the article lies in the formulation of a conceptual framework, termed the *strategic corporate investment cycle*. The model is inherently circular: it originates with strategic corporate investments and ultimately returns to them. Strategic investments stimulate corporate expansion; when investment decisions are rational and effectively implemented, companies optimize asset utilization, increase revenues, contain operating costs, and mitigate risks. Under such conditions, strategic corporate investments generate profit. Retained earnings, if not distributed, strengthen equity capital, thereby raising company value and augmenting shareholder wealth. At the same time, accumulated profits provide an endogenous source of financing for subsequent strategic investments – thus completing the cycle. Building on an extensive review of the relevant literature, the author explicates the constructs embedded within this conceptual model and positions them within the broader discourse on corporate finance and strategic management. The empirical analysis constitutes the core of the study. Using a combination of primary data from a representative survey of large and medium-sized Slovenian companies and secondary data spanning the period 2000–2017, the author applies rigorous statistical methods to test the proposed hypotheses. The results provide robust empirical support, leading to the full confirmation of all three hypotheses.The article concludes that strategic corporate investment decisions represent fundamental financial choices with enduring consequences. When accompanied by effective risk management, they not only secure sustainable long-term growth but also foster a continuous cycle of reinvestment, particularly in innovation. Within this dynamic, technological and managerial knowledge function as the *spiritus agens* that propels the perpetuation of the strategic corporate investment cycle.

Keywords: strategic corporate investments; company growth; innovations; company value; retained earnings; financial performance indicators

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1. Introduction

In this paper, we examine the impact of strategic investments on company growth, their value, productivity, and business performance, which is also the main objective of our research. The purpose of this article is to present the results of testing three research hypotheses related to the relationships mentioned above. We are particularly interested in strategic investments, as only these create value for the owners. The value of the owners' equity increases if the business generates profit and if this profit is not distributed in the form of dividends, but instead remains in the company as retained earnings and thus as a component of equity, while also serving as an internal

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source of financing for new investments. Of course, retained earnings and depreciation, as the highest-quality long-term sources for financing strategic investments, are not sufficient on their own. To finance strategic investments, a company must also seek external (debt) sources of funding (Bukvič, 2020). Profit in companies can be generated through sound management, on the one hand by increasing net sales revenue (we are concerned only with revenue generated from the company's core business activities, i.e., excluding financial and other income) and, on the other hand, by managing assets efficiently and reducing costs. A company can increase its net sales revenue either by raising prices – provided that its market position allows and permits it to do so (which in most cases it does not, as few companies hold a monopoly or oligopoly position in the market) – or by increasing productivity. Productivity growth can be influenced by employees through greater commitment, diligence, and a responsible attitude toward their work, particularly regarding the quality of products and services (so that there are fewer and fewer complaints from customers). To a large extent, however, productivity can also be improved through the so-called technical equipment of work – namely, the resources and technology employees use to produce goods and deliver services. If companies fail to keep up with the latest technological trends, such as today's digitalization of production and business processes, competitors will quickly overtake them, and the companies will be forced out of the market. The automation and digitalization of processes, along with the increasing integration of information and communication technology into company operations, is a necessary condition – a *conditio sine qua non*.

Such modernization and innovation, however, require certain expenditures – investments. If a company is to grow and develop, whether to maintain its market position or to increase its market share, it must invest continuously. Without investment, there is no growth. Investment in new machinery and equipment, in new production lines, in the development of new products and services, and in the innovation of processes, products, and services is indispensable if the company is to increase its sales volume, its revenues, and its economies of scale. In addition to organic growth, which is ensured by the above-mentioned investments, a company may also grow through acquisitions and mergers with other companies. This article does not address that area. It is, however, indisputable that innovation also contributes to company growth – investments in the innovation of products and services, in the innovation of production processes, in short, investments in all types of innovations – which we will present in more detail later.

The investments outlined above, including those in innovation, are referred to as *strategic corporate investments*. Strategic corporate investments influence the growth of net sales revenue, added value, and thus also the growth of profit, which, according to the principle of *quid pro quo*, increases the value of equity for the owners. In this way, we have closed the loop, which can be presented schematically as a simplified conceptual model in Figure 1.

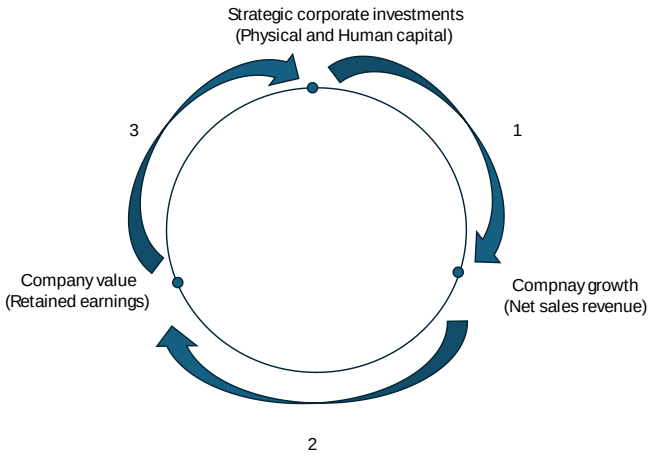


Figure 1. Strategic corporate investments cycle: strategic investments → company growth → company value (retained earnings) → strategic investments
Source: own work

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2025 Volume 13 Number 2 (December)
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The aim of the study is to traverse this cycle. We begin with strategic investments (the starting point), first presenting them in more detail, assessing and measuring their impact on company growth; then examining how, through the growth of operating revenues, they influence company value and thereby the owners' wealth; how they can increase productivity and improve business performance; and, finally, how the profit generated by strategic investments can be used by companies to finance new strategic investments (the end point). In conclusion, we find that the cycle turns continuously—*eppur si muove*! This cycle operates over time with greater or lesser uneven speed and intensity. For this reason, we refer to it as the *strategic corporate investments cycle.*

Following a brief introductory presentation of the purpose and objectives of this paper, along with the conceptual model, in Section 2 (*Literature Review*) we provide an overview of current literature sources in the field of strategic investments, growth, value, and profit – essentially following, in a clockwise direction, the cycle outlined above. We therefore examine in more detail both older and more recent scientific and professional articles in which the authors define strategic investments: what characterizes them, what is included among them, why they are important, and what their purpose is. This constitutes the first specific objective of our research.

In the cycle, company growth is the next area and the second specific research objective. Many researchers, academics, and corporate analysts have been engaged in this topic for years. They compare company growth to the growth of living organisms and attempt to identify the many factors that define or determine it. With the first arc of the cycle, we connect strategic investments and company growth, and on this basis we formulate our first research hypothesis.

The next area, and the third specific research objective we follow in the cycle, is company value. The first questions that arise are: What is company value? What defines and determines it? Which factors influence its increase? These questions have been addressed by many economists – from the classics and neoclassics to financiers and others. Here, we immediately touch on equity on the liabilities side of the balance sheet and its owners, who pursue a single objective: increasing their wealth. The first to ask what capital actually it was Robinson (1956), who systematically presented her theory of growth and capital accumulation within the post-Keynesian framework. She was followed by Ricardo (1817), Marx (1867), and other classical economists, who sought to provide a scientific basis for the concept of capital. This is, in fact, one of the most difficult questions in political economy. In this paper, we do not deal with this complex question; rather, we simply take capital as an accounting category. A very important part of it is profit – retained earnings, that is, the profit generated by the company's operations and kept within the company to finance its further growth. Such has been, and remains, a sovereign decision of the owners, who are aware that by reinvesting profit, they increase their future wealth.

With the second arc in Figure 1, we link company growth to company assets and retained earnings, and on this basis, we formulate our second research hypothesis. Before closing the cycle and returning to the initial area – strategic investments – in the final third of the cycle we pause at profit, as the fourth specific objective of our study. We have, in fact, already discussed it in the context of company value, where we noted that profit is the result of sound asset management and derives from increased net sales revenue (and, of course, from effective cost control), which expresses company growth – growth that is a consequence of strategic investments. In addition to increasing equity and the owners' wealth, profit plays another very important role in the cycle presented. It is precisely because of this role that we have highlighted it, within the context of company value, as a separate area of consideration in our cycle. Retained earnings in the company represent one of the highest-quality sources for financing long-term investments – that is, strategic investments.

With the third arc in Figure 1, we link the company's retained earnings to (new) strategic investments. In this way, we complete the cycle: strategic investments stimulate company growth – namely, net sales revenue – which, through increased profit, raises equity, i.e., the owners' wealth; a portion of this equity, referred to as retained earnings, then finances new strategic investments.

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2025 Volume 13 Number 2 (December)
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In this paper, we also aim to assess the productivity and financial performance of companies in relation to strategic investments, which constitutes the fifth specific objective of our research. We are interested in how strategic investments affect companies' productivity and certain financial performance indicators. On this basis, we formulate our third research hypothesis.

After thorough review of the relevant literature in Section 2 (*Literature Review*), we highlight a specific gap, which manifests itself in the lack of a systematic conceptualization of strategic corporate investments, the absence of a unified and more concise definition, as well as the insufficient integration of these investments with the constructs presented above, particularly in terms of their causal interrelations. In this study, we have addressed and meaningfully bridged these gaps, which may be regarded as our contribution to the scholarly discourse in the field of investment research. In Section 3 (*Research Methodology*), we first present the three research hypotheses, which we then test in the empirical part. We briefly introduce the research methods and techniques, separately for the theoretical and for the empirical part. We explain in more detail the approach and method of collecting both primary data (a questionnaire survey) and secondary data (the GVIN database). We highlight the limitations of our research, which also indicate directions for further studies in the field of strategic investments. In the empirical part, in Section 4 (*Research Results*), where we based our study on the examination of the above-described topics using the case of large and medium-sized Slovenian companies in the period 2000–2017, we sequentially test the three research hypotheses and explain the results obtained. These results were derived through statistical data processing using the SPSS 24 software tool. We present the results in both tabular and graphical form. Finally, in Section 5 (*Conclusion*), we first summarize two key novelties arising from our research, namely our conceptualization and definition of strategic corporate investments, and briefly introduce the conceptual model, i.e., the strategic corporate investment cycle. We then proceed to address the question of whether our research hypotheses can be confirmed. Finally, we emphasize the importance of technological and managerial knowledge as the driving force that continually propels and turns our strategic corporate investments cycle.

2 Literature Review

2.1 Definition of Strategic Corporate Investments

Investments are expenditures aimed at increasing or maintaining the stock of capital. Only net investments, which represent a real increase in capital, are considered here, since replacement investments or investment transfers do not increase the productive stock. Investments also play a developmental role, as they increase production capacities and influence economic growth. Investments mean the creation of additional productive capital and thereby offer the potential for increased production and economic growth.

Whenever investments are analyzed at the corporate level, the first question that arises is how much capital companies would like to use, taking into account the given costs and returns on capital use, as well as the intended level of output. What determines the desired capital stock –that is, the capital stock companies wish to have in the long term? Companies, of course, cannot immediately adjust their capital stock to the desired level needed for production; this requires a certain amount of time. We refer to this as the adjustment rate – the rate at which companies adjust from the existing capital stock to the desired level. The adjustment rate determines the rate of investment. Investments thus reflect the rate at which the economy adjusts to the desired state.

Such adjustment at the micro level includes, for example, the technological upgrading of production processes, such as the introduction of robotics in companies. Today, we are facing the fourth industrial revolution, with cyber-physical systems, the Internet of Things (IoT), artificial intelligence, and, above all, rapidly increasing production efficiency.

From the perspective of value-based management, company owners are interested in which strategies create value and which do not. Business logic should guide them in this. Weissenrieder (1998) classifies investments into two groups: strategic and non-strategic investments. Strategic investments are those aimed at creating new value for the owners and ensuring company growth. Non-strategic investments are those that maintain or preserve the value created by strategic investments. Strategic investments, such as investments in the development of a new product or in entering new markets, are followed by several non-strategic ones. A

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2025 Volume 13 Number 2 (December)
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strategic investment may be an investment in tangible fixed assets, which is the subject of our research, or in intangible assets. In this respect, it is irrelevant whether it is an investment expenditure or not. Anything in the company that counts as a cash expense and is connected with the creation of new value can, according to Weissenrieder (1998), be defined as a strategic investment.

According to Achim & Klein (2022), strategic investments are decisions on the timing and scale of risky, long-term investments whose implementation influences the learning (information) of other actors and the dynamics of competition. Barbieri et al. (2024/2025) distinguish strategic capital investments from routine ones based on several criteria: a high impact on future performance, large resource requirements, difficult and costly reversibility, and a long-time lag before effects become apparent. Therefore, the authors propose value-based models for the evaluation of strategic investments.

Strategic investments are large planned projects or investments that have a significant impact on the long-term development and growth of a company, organization, or country. They are aimed at improving competitiveness, expanding operations, introducing new technologies, or strengthening strategic advantages in the market. Examples of strategic investments include: purchasing key equipment or technology, developing new products/services, establishing new production facilities, expanding into new markets, investing in research and development, acquisitions, mergers, and takeovers of other companies or stakes in them. These investments are typically long-term, require careful planning, and involve relatively high capital expenditures. They are a strategic part of the company's long-term business or development strategy.

Capital-intensive investment projects can be relatively 'operational' in nature or have a more 'strategic' focus (Alkaaran & Northcott, 2006). 'Strategic' investment projects are significant investments that involve high levels of risk, yield difficult-to-measure (or undefined) outcomes, and have a major long-term impact on business performance. Typical examples include acquisitions and mergers, introduction of new major product lines, installation of new production processes, adoption of advanced manufacturing and business technologies, and significant changes in production capabilities (Van Cauwenbergh et al., 1996). The complexity and uncertainty of strategic investment projects present special challenges for managerial accountants responsible for their evaluation (Dempsey, 2003). It has been observed that excessive reliance on financial evaluation tools can lead to bias among decision-makers regarding strategic investment projects (Phelan, 1997). This can result in the rejection of investment decisions and may even hinder the development of innovation and the company's dynamic capabilities.

According to Snyder et al. (2025), strategic corporate investments include, but are not limited to, the following: (1) mergers and acquisitions – acquiring a company that can complement the existing acquiring company by increasing capacity, adding technology and intellectual property, expanding the customer base and geographic locations, etc., (2) research and development – investing in innovation and technology development to improve and expand the company's capabilities and offerings for existing customers and to attract new customers , and (3) ownership – purchasing ownership stakes in other companies or collaborating with other companies in joint ventures/projects to develop and expand products and technology by leveraging mutual strengths and resources. There are significant benefits of strategic investments that can contribute to the long-term growth and success of a company. According to Snyder et al. (2025), these benefits can be grouped into three categories.

Diversification
Strategic investments can lead to greater *sui generis* diversification, which reduces risk for the company. For example, customer concentration is a risk faced by many companies; it can cause problems as a significant share of revenue may be concentrated in one or two customers. Significant customer concentrations can also give customers greater control over prices and terms. If customers were ever to reduce a substantial share of their purchases from the company or leave permanently, this could seriously jeopardize the company's operations.

Market expansion
Any of the strategic investment initiatives mentioned above can, by themselves, lead to expanding the customer base and product range, as well as geographic presence. This allows companies to enter previously untapped markets, potentially increasing their revenue growth potential.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
https://doi.org/10.9770/k7580642657

Technology
Strategic investments can also be a means to develop and improve technology and intellectual property, which can increase the value of existing operations or act as a catalyst for developing new revenue streams or increasing revenue from existing customers.
According to Snyder et al. (2025), there can also be challenges in delivering strategic corporate investments, which include:

Financial risks
Strategic investments require capital, which can come from the company's own resources, external investors, debt, or a combination of all these sources. All of the strategic investments mentioned above demand a significant amount of capital and the engagement of all employees in the company if they are to succeed. If a strategic investment grows more slowly than expected or fails altogether, it can heavily strain the company and its resources.

Integration
This challenge is particularly significant in mergers and acquisitions. Every company has its own culture, and sometimes merging two companies leads to cultural conflicts or overlooked expectations. Other integration challenges can arise in human resources and information systems. Both require careful planning and well-organized execution (Bukvič, 2020).

Strategic corporate investments may also encompass so-called green investments. In recent years, a considerable number of scholars have addressed this topic (Ye & Dela, 2023; Ali et al., 2023; Ristanović et al., 2024). Green investments refer to capital allocations directed toward business projects that foster environmental protection, mitigate adverse ecological impacts, and promote sustainable development. Their purpose extends beyond the pursuit of financial returns – typically the primary concern of shareholders – to the generation of positive environmental and social outcomes. Corporate owners increasingly recognize that the long-term preservation and growth of their wealth requires that investment decisions be made with strict consideration of environmental and social dimensions. Representative examples of green investments include: (1) investments in renewable energy sources, (2) energy-efficiency projects, (3) sustainable mobility initiatives, and (4) waste management and recycling, among others. Green investments are generally subsumed under the broader category of sustainable investments, commonly referred to as ESG investments (Environmental, Social, and Governance) (Kansoy & Statiulaitis, 2025).

Tao et al. (2024) examine how strategic investments in green technologies affect the performance and profitability of companies in a supply chain when contractual agreements between partners are unobservable. The authors develop a theoretical model to demonstrate (1) when and why companies invest in green technologies, (2) how incomplete transparency of contracts influences investment decisions, and (3) which cooperation mechanisms can enhance sustainability and overall value in the chain.

Du et al. (2024) examine how companies in competitive markets make strategic technology decisions related to green technology opening, imitation, and investment. The authors analyze when it is more beneficial for companies to open their green technology, when to imitate competitors' solutions, and how these choices affect competitive advantage, sustainability, and profitability. They analyze the balance between openness, imitation, and proprietary investment in green technologies as key corporate strategies in competitive markets.

Carayannis et al. (2024) examine how integrating strategic innovation into environmental policy-making affects sustainable energy investments. The authors explore the economic impacts of this approach, highlighting that incorporating innovation into policy design can enhance the efficiency, profitability, and sustainability of investments in renewable and clean energy technologies. Finally, let us mention a few other aspects that significantly influence companies' strategic investment decisions. This involves a team-based approach in the preparation and simulation of strategic projects, the tax aspect of handling corporate investments, and global changes that are reflected in companies' investment policies and the shaping of their development strategies. Thus, Zhang et al. (2024) examine how strategic-oriented cohesion in multiteam systems influences enterprise

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
https://doi.org/10.9770/k7580642657

investment decisions. Based on an online simulation experiment using the CESIM platform – the CESIM platform is an interactive online simulation platform used in education and research for business and strategic decision-making – the authors show that stronger team cohesion improves decision alignment and leads to more effective corporate investment strategies. Yu et al. (2024) analyze how fiscal policy uncertainty affects companies' strategic investment decisions in China. Based on empirical data, the authors show that higher uncertainty regarding fiscal policy reduces companies' willingness to make long-term strategic investments and increases caution in their decision-making. Pohrebniak et al. (2023) examine strategic management of investment support for enterprises under global challenges. The authors analyze how companies can adapt their investment strategies and support mechanisms to maintain stability, competitiveness, and growth despite uncertainties in the global market.

In summary, *corporate strategic investments represent deliberate and well-considered allocations of resources, activities, or projects that enable companies to build new capabilities, expand in existing or enter new markets, and strengthen long-term efficiency and organizational stability.* They are oriented toward sustainable, long-term growth, and are intrinsically linked to the company's core business objectives and strategic vision, and as such in the long-run, they *enhance the value of the company and the wealth of its owners. Strategic c*orporate *investments frequently entail substantial capital commitments, including those in technology, research and development, innovation, digitalization and digital transformation, green investments (renewable energy, the circular economy and sustainable solutions), new production capacities, as well as mergers and acquisitions*. Although they involve a *relatively high degree of risk,* they offer significant potential for *generating durable competitive advantages*. Consequently, they demand *rigorous analysis* and *strategic decision-making* at the highest levels of corporate governance. The broader definition or conceptualization of corporate strategic investments presented above may be indicated and regarded as *an element of scientific novelty* and represents *a significant contribution to the field of investment research*.

2.2 Understanding Business Growth as their Imperative

Fasnacht (2009), in his article published in the book *Open Innovation in the Financial Services*, offered a vivid comparison of business growth to the growth of a living organism. In biology, growth is the increase in size and mass of an organism over a certain period of its development. Growth is often measured as an increase in biomass (the mass of organic matter), which can be linked to the differentiation of cells that manage specific functions within the organism. All organisms grow, although the rate of growth varies throughout their lives. Typically, an organism's growth follows an S-shaped curve, where growth is initially slow, then rapid, and toward the end of life, it essentially ceases. Growth can even be negative in the period preceding death.

In general, we cannot directly adapt definitions of concepts from nature to those in the business world. However, if we focus more closely on economic growth, we can observe similarities. Economic growth is understood as the increase in the value of goods and services produced by a given national economy. Since it is conventionally measured as the percentage rate of increase in real Gross Domestic Product (GDP), we could say that high growth reflects an increase in the average standard of living of individuals in a country. In recent years, we have observed a continuous increase in the number of wealthy individuals worldwide. These so-called high-net-worth individuals (HNWI) control an increasing share of global wealth. This is directly reflected in the GDP and market capitalization of a country. Market capitalization, in particular, has grown rapidly in Asia and Latin America, largely driven by foreign investments.

Growth is an imperative, not an option. There are several answers to the ultimate question: why grow? Whether we look at the perspective of the entire economy or an individual company, growth is important for maintaining competitiveness. It is necessary to maintain and increase market share. Growth also compensates for rising costs through economies of scale. If we view growth as an increase in wealth, we see that an increase in real assets managed by company leadership can partly be attributed to net cash inflows, which represent new funds, and partly to inflows generated by existing assets. Cash inflows can be considered organic growth of the company. Every growth of a company satisfies the increasing demands of all stakeholders related to that company (Fasnacht, 2009). Company owners are especially interested in high growth rates because it gives them confidence in their investments in the company. The cash accumulation generated by dynamic business growth is necessary for future investments, for example, in innovation, productivity increases, or business expansion.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
https://doi.org/10.9770/k7580642657

A company that has been growing for years is more attractive to suppliers and customers. Ultimately, growth creates jobs and contributes to economic prosperity (Fasnacht, 2009).

Fasnacht (2009) argues that growth remains crucial, but the way growth occurs has changed. Today, we must recognize sustainable growth, which takes place through the differentiation of competitors, high-quality products and services, and the satisfaction of customers and employees. The key sources of a company's competitive advantage are quality in products and services, brand, and marketing. Furthermore, it is important to distinguish between growth strategies that focus on marketing new or existing products/services in new or existing markets. Therefore, companies must become more innovative in choosing different ways to grow. This means employing new technologies, continuously improving products, services, and processes, and managing human resources more efficiently. According to Fasnacht (2009), the message to companies operating in a highly competitive global environment is quite simple – perform better than others. A company's successful operation is reflected in investors' willingness to invest in that company. Of course, growth in net sales revenue alone is not sufficient. It is therefore necessary to continuously monitor the profitability of products/services and also the performance of all stakeholders within such a company.

2.3 Strategic Corporate Investments and Growth

When companies seek growth opportunities, owners and stakeholders must develop strategies to achieve their goals and enable returns to these individuals (Snyder et al., 2025). With strategic investments, owners and stakeholders should focus on opportunities to increase revenue, strengthen their market and geographic presence, acquire talent, and develop and improve technology and intellectual property.

Some authors (Desai et al., 2011) have examined several contemporary theories in more detail to verify whether increasing or decreasing strategic corporate investments can contribute to returns for owners. They arrived at several interesting findings related to how potential investment decisions affect business growth. They demonstrated that there is a connection between investment decisions and their effects. Growth opportunities influence a company's assets and profitability.

In the resource-based theory, differences in company growth are primarily attributed to internal resources and dynamic capabilities (Barney, 1991; Grant, 1991). Although company growth depends on external conditions, according to these authors, internal factors are the main determinants of growth. Similarly, Wright et al. (1996, p. 444) argue that "some firms may have growth opportunities because of valuable internal resources or because of their position in attractive industries." Desai et al. (2011), through their study, demonstrated that growth opportunities for an individual company create the potential benefit of further internal investments in that company. Consequently, it can be argued that some companies have growth opportunities while others may not, depending on whether their internal resources and capabilities are valuable, rare, imperfectly imitable, or imperfectly substitutable (Bukvič, 2020).

Other authors take a more realistic view of the company and its growth potential. For example, according to the theory of industrial organization, differences in growth opportunities among companies are to be expected (Barney, 1991). According to this theory, differences in growth rates are largely attributed to industry entry conditions and mobility barriers (Caves & Porter, 1977). These barriers typically limit the number of competitors, allowing greater company growth. Axiomatically attractive industries usually have relatively high barriers, while unattractive industries have low barriers. Moreover, studies on strategic corporate investments have concluded that aggregate characteristics of an industry can influence the profitability of such investments. This is particularly true for high-technology industries (Chan et al., 1990).

Doukas & Switzer (1992) argue that strategic investments have a greater positive impact on company growth in more concentrated industries. Studies of strategic investments that depend on industry characteristics assume that the nature of a particular industry fully reveals whether further internal investments are beneficial for a company or not. It can be summarized that industry characteristics strongly determine the potential benefits of further investments, while recognizing that companies within the same industry have different expectations from their investments. Studying strategic investments within an industry independently from studying the

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
https://doi.org/10.9770/k7580642657

effects offered by growth opportunities is quite limited and does not provide a good basis for research in this area.

Spence (1979), in his article, addresses strategic investment decisions of companies entering a new industry or new market. By new industry or new market, he means a potential market that has emerged due to technological innovation, changes in relative prices, or similar events. In such a market, supply is lower than demand, so there are significant growth opportunities for companies without the need to create excess capacity. This can be called the growth phase in the market life cycle, which differs from the mature phase. The growth phase is characterized by high levels of entries and exits.

2.4 Strategic Corporate Investments and Maximizing Company Value for Owners through Profit Generation

Optimizing a company's value is its primary goal (Jensen & Meckling, 1976). According to Park & Byun (2022), a company's value is expressed as the performance of management and business operations entrusted by the owners to the agents (the management). What owners expect from the agents is an increase in the company's value, as their wealth grows along with the company's value. Jensen (2001) argues that company owners pursue the maximization of the company's value in the long term. The value (net worth) of a company is also an important indicator of its investment ability (Bukvič, 2020).

Investment decisions are one of the factors that can increase a company's value (Fama 1978). Studies on the impact of investment decisions on company value have been the subject of much discussion over the past few decades, both in countries with emerging markets and in those with less developed markets. A sample of research conducted in the 1990s showed that investment decisions could indeed increase a company's value (Bajo et al., 1998; Santos et al., 1993). On the other hand, research from the 2000s showed that investment decisions generally hindered value growth (Brio et al., 2003; Lin & Kulatilaka, 2007). In the 2010s, numerous authors (Efni, 2017; Soumaya, 2015; Susanti et al., 2019) found that increases in company value could be attributed to investment decisions. Based on these observed patterns, it can be concluded that company value can be increased through rational investment decisions. The theory of signaling wealth, which underlies investment decisions (Alghifari et al., 2022), explains that investment spending is a positive signal. leading to future company growth. This, in turn, affects profits and, if these profits are not distributed among owners, leads to increased equity and thus greater company value.

According to Tan & Luo (2021), investment decision-making is one of the most important functions of a company, as investment activity affects the composition of assets and, consequently, the capital structure of the company. The decision to invest capital in a proposed project must be evaluated and adjusted to the level of risk and expected returns (Liu & Zhang, 2020). The rate of return, when adjusted to a manageable and controllable risk level, is expected to increase the company's value. Based on signaling theory (Fathi et al., 2024), the role of two parties is highlighted – the "signaler" and the signal receiver. Company management sends a signal to the financial market in the form of information related to investment decisions, showing that the company is successfully pursuing its long-term growth (Modigliani & Miller, 1958). This can increase the company's value, ultimately benefiting shareholders' wealth. This claim is supported by numerous studies, including Susanti et al. (2019), Al Daas et al. (2020), Pramartha et al. (2020), who found that investment decisions influence company growth and value.

Company's growth can be expressed through the dynamics of net sales revenue. Profitability shows the size of the profit associated with investments or sales (Tao et al., 2020). It also reflects the ability of management to generate profit for the company and its owners, and it serves as a measure of managerial efficiency (Amarundin et al., 2019). High profitability indicates that the company has good prospects for the future (Yondrichs et al., 2021; Handayati et al., 2022). This is a positive signal for investors to commit their financial surpluses to such companies. Profitability has a significant impact on the level of financial liquidity and financial security. Therefore, when analyzing a company's profitability, investors should also pay attention to its financial liquidity. In the case of long-term investments, investors are increasingly analyzing financial security alongside profitability levels. Investment decisions supported by high profitability, in terms of providing quality internal

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2025 Volume 13 Number 2 (December)
https://doi.org/10.9770/k7580642657

financial resources, strengthen the company's reputation in the eyes of investors. Investor interest in a profitable and growing company contributes to increasing its value (Alghifari et al., 2022).

2.5 Profitability of Strategic Corporate Investments – A Factor in Increasing Company Value and Owners' Wealth

Based on the theory of value-based management, the primary goal of any company is to increase its value (assets) and generate above-average returns for its owners or investors, thereby increasing their wealth. In today's dynamic and competitive environment, where changes in capital markets are constant, companies must also change quickly and radically, in fact, continuously adapting to new market conditions. Financial markets constantly pressure company management to drive growth – and even more, to ensure that their companies remain in continuous global growth. To achieve the expected returns for owners in the future – that is, returns exceeding the risk-adjusted market average – companies must grow faster than their owners expect. As repeatedly emphasized, such growth can largely be ensured through strategic investments. Simply put, a decline in share price can only be prevented if the growth rate exceeds expected growth and if that growth is profitable. The ratio between the market price of a share and its earnings per share, known as the P/E ratio or multiplier, is a good measure of performance and a reliable indicator of how well a company is doing and how successful its strategic investments have been. The P/E ratio can serve as an indicator of operational problems or as a sign of business opportunities. It can be used to analyze the market value of a company's shares compared to the wealth it actually generates.

For example, if one share has a P/E ratio twice as high as another share, it means that it is a less attractive investment for investors. However, caution is required when comparing this ratio across industries, countries, and time periods. Comparisons should be made between similar shares. Historically, for example, the average P/E ratio in the private banking sector was around 15, compared to 10–12 for general universal banks (Fasnacht, 2009). Today, this ratio stands at 12.7, and 17.85 for the financial sector (World PE ratio, S&P 500 Financials). In banking, the ratio has always been considerably lower than in high-tech industries.

Market estimates of this ratio for many large banks have in recent years fallen well below ten. In a normal market environment, this would mean that such shares are cheap relative to their earnings and therefore a clear signal to buy. The problem lies in the uncertain future of these companies. There are several reasons why a share might have a high P/E ratio. For example, in the summer of 2005, Google's P/E ratio exceeded 100; today, in 2025, the ratio stands at 21.45 (Megatrends, 2025). This is typical for companies that have not yet generated high profits but are expected to do so in the coming years. In such cases, the market expects rapid profit growth in the future. Conversely, a high P/E ratio can also be explained by the fact that a company generated high profits in the past but also incurred high one-time costs. Shareholders usually understand that such issues are one-off and continue to buy the shares at the same price as before, selling them at least at that same price. Additionally, a share may have a high price due to high demand that is unrelated to the company itself – for instance, if an institutional investor is attempting to diversify risk. These are just some of the factors that influence the P/E ratio.

Buchbinder (2025) argues that the P/E ratio is more useful for long-term market forecasts and less so for short-term predictions. According to him, a high P/E ratio has greater predictive value over a ten-year horizon. Some financial experts (Fasnacht, 2009) interpret this ratio, or multiplier, in two ways – once considering company growth and once without it. In the first case, the P/E ratio mainly reflects the company's current operations, meaning it continues to operate as it always has and is expected to do so in the future. In the second case, when growth is taken into account, the P/E ratio reflects market expectations regarding the profitability of the company's future investment opportunities. This gives investors confidence that they can expect promising returns on their investments in the company. In fact, roughly four factors determine whether a company's growth, in terms of profitability, will be high, moderate, low, or even negative. Any action by company management aimed at increasing the share price and P/E ratio influences one of these factors.

First, return on invested capital together with the cost of capital measures the true profitability of future investment opportunities. This financial metric simply shows how well the company generates cash flow relative to the capital invested in it. Second, the investment amount – that is, the sum of money exceeding

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2025 Volume 13 Number 2 (December)
https://doi.org/10.9770/k7580642657

depreciation and reinvested annually into operations and new strategic investment projects – is another important growth factor that can increase or decrease the P/E ratio. For a company to grow, investments must be large enough (net investments) to maintain the real value of assets, such as long-term tangible fixed assets. Ideally, investments should exceed the amount of depreciation. Finally, the time factor is also important – that is, the period during which the company can sustain the profitability of its new strategic investments at a level exceeding the cost of capital. A company can achieve any given P/E ratio through different combinations of the four factors. However, among competitors, the company with a P/E ratio above the market average will be the most attractive for attracting capital for its sustainable growth.

Although this may seem logical, numerous studies (Fasnacht 2009, and others) show that approximately 90 % of all public companies in developed economies are unable to sustain growth for more than a decade – at least not growth that delivers above-average returns for shareholders. Christensen & Raynor (2013), in their book *The Innovator's Solution*, revealed this growth paradox. Based on their own research and numerous studies, they concluded that growth and innovation are interdependent. According to them, failure to sustain growth is not the result of a lack of great ideas, unpredictable innovations, or capable managers, nor of changes in the nature of demand and unusual customer responses. Sustainable growth fails because companies prematurely eliminate the disruptive potential of innovations before they even see the light of day. In addition, companies must be profitable. The question remains, then – what actually creates value? The third factor that companies must consider if they wish to maintain sustainable growth, profitability, and value is risk. The concept of risk is independent of the concepts of growth, profitability, and company value. For example, in financial markets, we measure credit risk – the risk of loss due to the borrower's insolvency. In the field of financial investments, there is a relatively large range of financial instruments used to hedge against risks. Business risk is a reality and must be taken extremely seriously, especially during periods of high growth, even though certain risks are difficult to manage. To increase growth and profitability while successfully managing risks, companies must leverage the synergy between employees, processes, and strategies. Company leadership must mobilize the workforce to pursue ambitious goals with full commitment, in line with risk management measures. This stems from a corporate culture in which performance is regarded as a value and which relies on exceptional leadership (Fasnacht, 2009).

Although company management is forced to constantly analyze the impact of various risks on operations (and maintain a risk register), it must at the same time focus on innovation if it wants to ensure sustainable, profitable growth. Innovation is thus the fourth factor that drives company growth. Innovations, as strategic investments – often the only ones capable of meeting shareholder demands for growth – require taking on risks. To succeed in this, company leadership must understand the forces that generate innovation. Managing change, innovation, and growth while simultaneously monitoring costs and risks presents a major challenge for company management. This makes it necessary to better understand the key growth strategies and actions that lead to success based on innovation. This supports the theory that growth can be achieved through mergers and acquisitions, alliances, joint ventures, or organically.

2.6 Innovation as a Strategic Corporate Investment – A Driver of Growth and an Enhancer of Company Value and Shareholder Wealth

Recognizing innovation as a key driver of growth seems, in itself, quite logical. What is essential, however, is to understand the process that reveals which innovations lead to company growth. This is important because growth can only be achieved if it is aligned with the company's innovation strategy. The word *innovation* is understood in various ways, which is why the literature offers different interpretations. Without delving into the Latin verb *innovare*, meaning "to make something new," we can state that innovation is a term broadly used for any type of novelty. In a business sense, it usually refers to introducing a new product or service to the market or improving existing ones. This inevitably entails the need to invest in and finance such strategic investments. In any case, innovation applies not only to products and services but also to concepts, strategies, and paradigms (Fasnacht 2009). Innovations appear in many different forms – from truly revolutionary to almost everyday. They include creating new forms and methods of work, their commercial exploitation, and their subsequent diffusion into the economy and society. Innovations – especially when implemented in companies as strategic investments – are among the main drivers of long-term economic growth and structural change and always promote economic progress. According to Fasnacht (2009), innovations can be understood as (1) the renewal

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
https://doi.org/10.9770/k7580642657

and expansion of the range of products and services and related markets, (2) the development and introduction of new methods of production, supply, and distribution, and (3) the introduction of changes in management, work organization, working conditions, and employee knowledge. Understanding innovation depends on the perspective from which it is viewed. In economic terms, an innovation must increase value for the company, the consumer, or the producer. For consumers, innovation means higher quality and greater product value, more efficient services, and a higher standard of living. Companies expect more efficient production processes, more economical management of long-term assets (Bukvič, 2020), improved business models, or new products and services – all of which lead to sustainable, enhanced growth and higher profits for owners and investors.

Today, researchers such as Judijanto et al. (2025) focus on the resilience of strategic investments during economic recessions, emphasizing diversity (in products, markets, regions) and innovation as a tool for improvement. Some empirical studies from the Asia–Pacific region demonstrate that strategic investment – sometimes even referred to as "responsible" investments – have a significant positive effect on innovation and corporate performance.

Employees can benefit from innovation through new and more interesting work, improved skills, and higher wages. From an organizational perspective, companies would not survive without innovation, as new products and services and new or improved ways of doing business are essential for business continuity and growth. Without innovation – or if innovations fail – there is no differentiation, no expected profit, and no potential investors. In short, innovations understood as strategic investments *sui generis* represent the creation of value and the increase of productivity in any industry and economy. Innovation can lead to higher revenues, improved added value, and greater sustainable competitive advantage. Since the creativity and inventiveness of companies are the greatest assets available to a national economy, innovation is the key to higher productivity and greater prosperity for all.

2.7 The Impact of Strategic Corporate Investments on Productivity and (Non-)Financial Business Performance

There is a considerable body of literature examining the relationship between adjustments to a company's capital – understood as increasing its assets through investment – and its business performance, as measured by productivity and growth rate (Hugget & Ospina, 2001; Nilsen et al., 2009; Shima, 2010), employment growth, sales growth, or other production factors. These authors, through more sophisticated research on French and Italian companies, have demonstrated that investments indeed improve business performance. A strategic investment is expected to influence productivity in the long run, as new capital incorporates the latest technology (Jensen et al., 2001). Models that adhere to the principle of *learning by doing* predict that it takes time for workers to learn how to use new technology. As a result, labour productivity following a strategic investment will most likely take on a U-shaped curve – initially declining, then gradually increasing to a level higher than before the investment. Grazzi et al. (2013) also examined the effects of large strategic investments on company performance. There are multiple reasons why companies invest in tangible fixed assets – for example, to meet growing demand, to mitigate technological obsolescence by acquiring new equipment, or to introduce to the market a new product line that requires more advanced equipment. Therefore, such investment efforts would be expected to correlate positively with company size, company growth, and overall business performance.

Using a different econometric approach, Nilsen et al. (2009) found a positive and significant effect of investments made within the same year on labour productivity. Interestingly, these effects dissipated in the following years. Similarly, the same authors identified a positive relationship between strategic investments and both sales growth and profitability.

Critics of financially oriented business performance assessment models, at the end of the last century, highlighted the one-sidedness of financial indicators (Kaplan & Norton, 1992). Financial indicators became insufficient for assessing the performance of companies experiencing rapid technological change, increased innovation and flexibility, and shorter product life cycles. As a result, many authors – such as Kaplan (1983) and Eccles (1991) – advocated the inclusion of non-financial indicators derived from corporate strategy, which could offset the limitations of financial metrics.

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2025 Volume 13 Number 2 (December)
https://doi.org/10.9770/k7580642657

In the current era of digitalisation, some authors (Buglea et al., 2025) examine the impact of digital transformation on non-financial performance indicators, emphasising environmental, social, and governance (ESG) aspects of business performance in Central and Eastern European countries. Alves & Lourenço (2022) explore how small and medium-sized enterprises (SMEs) incorporate non-financial metrics – such as customer satisfaction, product/service quality, innovation, and employee productivity – into managers' compensation systems. Based on empirical data, they find that non-financial metrics are often used alongside financial indicators, particularly in companies with long-term strategic goals, where monitoring quality and innovation is crucial, and where financial results alone do not fully capture performance.

Conversely, Zarzyka & Krasodomska (2021) investigate whether certain company characteristics – both internal and external factors – influence the quality and extent of non-financial performance disclosures. While companies disclose a wide range of non-financial indicators, such diversity complicates comparability. Nonetheless, non-financial indicators contribute to explaining the factors underlying achieved performance – this also applies to a company's investment activities, although these are not discussed in detail here. Although many companies strive to improve operational efficiency and aim to increase average return on equity (ROE), they often find it challenging to maintain efficiency in terms of the cost-income ratio (CIR). Enhancing operational efficiency is generally less demanding than pursuing growth, as growth exposes companies to higher risks and greater demands for innovation. Therefore, it can be argued that growth rather than profitability is the primary driver of increased market capitalisation. To assess profitable growth, one must connect value and profitability. Net sales revenue, net profit, as well as ROA and asset growth, are just some of the indicators that reflect a company's business performance. Many companies continuously expand their assets, but only a few manage to increase ROA alongside asset growth. On one hand, it could be argued that growth can only be achieved if mergers and acquisitions are part of a company's strategy. On the other hand, organic growth is also necessary. Regardless of the strategy, profitability must always be considered. Organic growth may be the only realistic option when there is no company available for acquisition or merger. Pursuing organic growth in mature markets while successfully acquiring businesses in high-growth markets may prove to be a prudent choice for companies.

A comprehensive review of the literature on the impact of strategic investments on corporate performance reveals that a considerable body of research and scholarly articles has examined how investments foster the growth of both enterprises and the economy as a whole, enhance productivity, and improve working conditions – thereby contributing to their humanization – while simultaneously expanding corporate assets and increasing shareholder wealth, and ultimately advancing societal well-being. Nevertheless, within the existing body of research, there are relatively few studies that explicitly distinguish between strategic and non-strategic investments and analyze them separately. The prevailing approach instead tends to classify investments into financial and productive categories, or into investments in financial versus real assets.

In recent years, increasing scholarly attention has been directed toward investments in knowledge and human capital. Consequently, the distinction between investments in physical capital and those in human capital has become increasingly salient. Recent studies (Paczos et al., 2023) suggest that the rates of return on human capital investment may surpass those associated with physical capital. Nevertheless, national accounts conventionally classify expenditures on human capital as consumption, recognizing only physical capital formation as investment. The aforementioned authors have developed a methodology for the classification of such expenditures and applied it to data on public and private spending across 28 EU member states. Their analysis indicates that, on average, human capital investment amounts to 11.1 % of GDP, with 8.8 % originating from the public sector. By comparison, physical capital investment accounts for 20.6 % of GDP, of which 17.6 % is attributable to the private sector. A narrowly defined conceptualization of investment may therefore result in an undue emphasis on the accumulation of physical capital at the expense of the potentially higher-yielding investment in human capital.

Despite the insights outlined above, a gap remains in the scholarly literature concerning how to conceptualize strategic corporate investments in an integrated manner – specifically, how to link them to company growth, value creation, and the accumulation of shareholder wealth, as well as how to reinvest the returns generated from investment into subsequent investment cycles, thereby positioning them as a driving force of growth.

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2025 Volume 13 Number 2 (December)
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3. Research Methodology

In this chapter, we present the quantitative methodology used, in which the stated hypotheses were tested with the help of the SPSS program. The data was obtained from a questionnaire and the publicly available GVIN database.

3.1 Research Hypotheses and Research Methods

In the study, we formulated, among others, the following research hypotheses:
H1: Strategic investments are the greatest driver of company growth.
H2: By generating profit, strategic investments increase the value of companies.
H3: Strategic investments increase productivity and improve business performance.

In the theoretical part of the study, we used the scientific method of description as well as scientific methods of classification, comparison, analysis, and synthesis. In the empirical part of the study, we applied statistical methods (descriptive statistics, contingency tables, Chi-square test, T-test, and linear regression) and processed the data using the SPSS 24 statistical package.

3.2 Financial Indicators

In our research, we used financial performance indicators derived from accounting data for selected companies in the sample. The financial indicators in our study are: net sales revenue per employee, value added per employee, EBITDA margin, EBITDA compared to assets, return on equity or ROE, return on assets or ROA, net profit margin, cost-effectiveness (Operating revenue / Operating expenses), and net financial debt compared to EBITDA. With the exception of the last indicator, all the above represent measures of financial performance.

3.3 Data Collection Method

The data was collected at a specific point in time (cross-sectional data). This method is suitable for types of research aimed at finding connections between certain phenomena or factors. Since our objective was to examine the relationship and effects between strategic investments and company growth and company value, and consequently on business performance, in this case it was more appropriate to analyze data referring to the same point in time rather than data collected sequentially over time (longitudinal data). Another important reason for choosing this research method was the fact that it has been used in most studies in the examined field, particularly regarding the impact of the dynamics and scope of strategic investments on productivity and business performance, which allows the results of our study to be, to some extent, comparable with those of others.

We used both primary and secondary data. Primary qualitative data was collected through a questionnaire. A total of 267 questionnaires were correctly completed (23.38 % of all respondents). Quantitative data was obtained from the published annual reports of companies in the Slovenian economy, specifically those operating in categories A to J according to the Slovenian Standard Classification of Activities (SKD 2008, V2). Secondary data was obtained from the GVIN database.

The sample included only large and medium-sized Slovenian companies. Large companies are those that meet at least two of the following criteria: the average number of employees in the last financial year exceeds 250, net sales revenue in the last financial year exceeds 40 million €, and the value of assets at the end of the financial year exceeds 20 million €. Medium-sized companies are those that meet at least two of the following criteria: the average number of employees in the last financial year exceeds 50 and does not exceed 250, net sales revenue in the last financial year exceeds 8 million € and does not exceed 40 million €, and the value of assets at the end of the financial year exceeds 4 million € and does not exceed 20 million € (Article 55 of the Companies Act, ZGD-1-NPB14).

The representativeness of our sample is demonstrated by the data in Table 1, Table 2, and Table 3, which show the characteristics of the companies in the sample compared to the overall population (the Republic of Slovenia). The basic research also includes a presentation of the sample companies by age, their legal and organizational status, ownership structure, and the form and manner of their management (Bukvič, 2020).

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
https://doi.org/10.9770/k7580642657

Table 1. Size of Sample Companies According to Article 55 of the Companies Act (ZGD-1-NPB14)

Company size	Sample (Questionnaire)		Republic of Slovenia		Δ
	#	in %	#	in %	
Big	78	29,21	336	29,42	-0,21
Medium	189	70,79	806	70,58	0,21
Total	267	100	1 142	100	0

Source: Investment ability of the companies, questionnaire 2018

Table 2. Overview of Companies by Region

Region	Sample (Questionnaire)		Republic of Slovenia		Δ
	#	in %	#	in %	
Osrednjeslovenska	77	28.84	406	35.54	-6.70
Podravska	27	10.11	133	11.65	-1.54
Savinjska	50	18.73	125	10.95	7.78
Gorenjska	25	9.36	108	9.46	-0.0
Jugovzhodna Slovenija	19	7.12	71	6.22	0.90
Goriška	11	4.12	64	5.60	-1.48
Obalno-kraška	16	5.99	58	5.08	0.91
Pomurska	12	4.49	56	4.90	-0.41
Koroška	9	3.37	38	3.33	0.04
Posavska	10	3.75	36	3.15	0.60
Primorsko-notranjska	5	1.87	29	2.54	-0.67
Zasavska	6	2.25	18	1.58	0.67
Total	267	100	1 142	100	0.00

Source: investment ability of the companies, questionnaire 2018

Table 3. Predominant activity according to the Standard Classification of Activities (SKD 2008, V2)

Core activity	Sample (Questionnaire)		Republic of Slovenia		Δ
	#	in %	#	in %	
Manufacturing activities	130	48.70	489	42.82	-5.88
Trade, maintenance and repair of motor vehicles	60	22.47	334	29.25	6.78
Transportation and storage	18	6.74	80	7.01	0.27
Construction	14	5.24	63	5.52	0.28
Hospitality	13	4.87	32	2.80	-2.07
Water supply, sewerage, waste management and remediation activities	11	4.12	40	3.50	-0.62
Electricity, gas and steam supply	11	4.12	29	2.54	-1.58
Information and communication activities	7	2.62	48	4.20	1.58
Mining	2	0.75	7	0.61	-0.14
Agriculture and hunting, forestry, fishing	1	0.37	20	1.75	1.38
Total	267	100	1 142	100	0.00

Source: investment ability of the companies, questionnaire 2018

The study focuses on the period from 2010 to 2017, with certain sections covering the extended period from 2000 to 2017 (to compare the growth of tangible fixed assets with selected financial categories). The data were collected on an annual basis for each year within this period. During the research process, we identified the

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
https://doi.org/10.9770/k7580642657

variables to be measured, established the measurement scale (using a 7-point Likert scale), developed a questionnaire, and tested it for both reliability and content validity.

3.4 Limitations

It is important to acknowledge the limitations encountered in this study, primarily relating to the empirical component. The first limitation concerns the sample size, as the research was conducted exclusively on Slovenian companies. An international study would have included a larger number of larger companies, where the impact of strategic investments is typically more pronounced. Relevant literature informed our assumption regarding the direction of causality in our conceptual model (the effect of strategic investments on company growth, value, and business performance). As the study relied on cross-sectional data, direct causality cannot be established. Determining the direction of causality would require a longitudinal study, which presents a potential avenue for future research. The second limitation pertains to the size of the companies studied, which are relatively small compared to international competitors. Consequently, the average size of their strategic investments is smaller than that of foreign companies. This limitation is particularly evident for medium-sized companies, which were also included in our sample. The third limitation, specific to this paper and largely due to space constraints, is the exclusion of non-financial indicators of business performance in relation to strategic investments. The fourth limitation relates to potential subjectivity, as typically only one individual completed the questionnaire (usually the CFO, and in some cases the company director or another senior management member).

4 Research Results

4.1 Testing Research Hypothesis H1 on the Impact of Increased Strategic Investments on Company Growth

In the following, we present and summarize the results of the study. We first test the research hypothesis that an increase in strategic investments affects company growth. In our research, strategic corporate investments are defined as investments in tangible fixed assets only, while company growth is measured by the growth in net sales revenue. For this analysis, we consider a longer time series for the companies in our sample, specifically the period from 2000 to 2017. Company growth can also be expressed using other financial indicators, such as value added and EBITDA, although these measures primarily reflect business performance, as they already take operating expenses into account. To this end, it is first necessary to prepare the relevant data. We rely on the AJPES database based on the chart of accounts. For tangible fixed assets (OOS), we use annual data from account 0010102, and for net sales revenue (ČPP), we use annual data from account 050. Account 0010102 shows the undepreciated book value of tangible fixed assets. This value naturally changes continuously, both within a year and across years. It is affected by depreciation, i.e., the write-off of the value of tangible fixed assets, and by the disposal of tangible fixed assets (divestment), both of which reduce the balance. Conversely, it is affected by purchases or acquisitions of new tangible fixed assets, including acquisitions under long-term financial leases. As mentioned, we disregarded any revaluation effects of tangible fixed assets for the companies in our sample.

If the difference between the acquisition cost of new tangible fixed assets and the depreciated value of existing tangible fixed assets or the value reduced due to divestment is positive, this is considered net investment in tangible fixed assets. By examining this balance, i.e., the undepreciated value of tangible fixed assets, over a longer period, we can determine from the differences (or chain indices) whether companies made net investments or divestments in each year. The difference between two annual balances (at the end of each calendar year, as of December 31) of the undepreciated value of tangible fixed assets, $OOS_t - OOS_{t-1}$ (account 0010102), represents net investments in tangible fixed assets in year t. Since the analysis covers a long period and to ensure data comparability over time, all values are appropriately adjusted using deflators or inflators for each year (SURS – Inflation Adjustment for the Period 2000–2017). For the entire sample (267 companies), we calculate the annual average values for both of the categories mentioned above. For each company included in the sample, we calculate chain indices and, based on them, the average growth rate of each economic category. In doing so, we use the geometric mean, which is calculated according to the following formula:

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2025 Volume 13 Number 2 (December)
https://doi.org/10.9770/k7580642657

$$(\prod_{i=1}^{n} a_i)^{\frac{1}{n}} = \sqrt[n]{a_1 a_2 a_3 \ldots a_n}$$

In the calculation of a simple linear regression, we consider tangible fixed assets (OOS) as the independent variable and net sales revenue (ČPP as the dependent variable, using the annual average values calculated for each year. The calculation is presented in Table 4.

Table 4. Linear Regression Calculation for the Dependent Variables OOS and ČPP

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,821[a]	0,673	0,652	4054964,139

a. Predictors: (Constant), Tangible fixed assets

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	5,085E+14	1	5,085E+14	30,926	,000[b]
	Residual	2,466E+14	15	1,644E+13		
	Total	7,552E+14	16			

a. Dependent Variable: Net sales revenue
b. Predictors: (Constant), Tangible fixed assets

Coefficients[a]

Model		Unstandardized B	Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	-23654658,1	9981459,460		-2,370	0,032
	Tan. fix. assets	1,505	0,271	0,821	5,561	0,000

a. Dependent Variable: Net sales revenue

Bootstrap for Coefficients

Model		Bootstrap[a] B	Bias	Std. Error	Sig. (2-tailed)	Bca 95% Confid. Interval Lower	Upper
1	(Constant)	-23654658,1	-818984,712	11901364,94	0,116	-47733387,8	-666241,520
	Tan. fix. assets	1,505	0,027	0,338	0,012	0,894	2,193

a. Unless otherwise noted, bootstrap results are based on 1000 bootstrap samples

R^2 has been calculated as 0.673, which means that investments in tangible fixed assets account for more than two-thirds of the variation in net sales revenue. In other words, if we try to explain why companies increase the sales of their products, services, or goods/materials, we can look at the variation in net sales revenue. There is a whole range of factors that can explain this variation, but our model, which includes only investments in tangible fixed assets, can account for 67 % of it. This means that slightly less than one-third of the variation in

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
https://doi.org/10.9770/k7580642657

net sales revenue cannot be explained by investments in tangible fixed assets. Of course, other factors and variables also influence the increase in product/service sales volume.

In the analysis of variance (ANOVA) presented above, the sums of squares and degrees of freedom are provided. From these two values, we can calculate the mean squares by dividing the sums of squares by the corresponding degrees of freedom. The most important part of this table is the F-statistic, which equals 30.93 and is significant at $p < 0.001$ (since the value in the column labeled "Sig." is less than 0.001). This result indicates that the probability of obtaining an F-statistic of this magnitude is less than 0.1 % if the null hypothesis were true. Therefore, we can conclude that our regression model is a much better predictor of the increase in net sales revenue than simply using the average net sales revenue. Overall, the regression model predicts movements in net sales revenue very well. This result is logical and expected.

We can ask why companies invest, why they allocate funds to purchase equipment, machinery, or to build new production or storage facilities. The answer is that new business opportunities arise in the market, with increased demand for their products or services. By expanding production and other capacities, increasing retail space in trade, or expanding vehicle fleets in transport and logistics, companies increase their resources to grow their sales volume, which in turn also increases net profit. Other factors, beyond the increase in tangible fixed assets, that affect higher sales volume and thus company growth, but are not considered in this study, may include price increases, productivity improvements (higher output per unit of time), export incentives or customs relief, business process optimization, organizational changes, and so on.

ANOVA shows whether the model predicts the outcome variable well, but it does not reveal the individual contribution of variables – except in our model, which includes only one independent variable. The calculation shows the estimates of the model parameters (beta values) and the significance of these values. In the equation above, b_0 represents the intercept on the ordinate axis and corresponds to the constant B. Here, b_0 is 23.6 million €. This can be interpreted as follows: if companies do not spend a single euro on investments in tangible fixed assets ($X = 0$), the model predicts that all companies in our sample would decrease their net sales revenue by 23.6 million €. In the same table, we can read the value of b_1, which represents the slope of the regression line and equals 1.505. Although this value represents the slope, it is more useful to interpret it as the change in net sales revenue resulting from a 1 € change in investment in tangible fixed assets. For example, if investments increase by 100 €, net sales revenue from products/services would increase by 150.50 €, which can be considered a relatively good result, given that increases in investments in tangible fixed assets contribute more than two-thirds to the growth of net sales revenue. Let's look at the t-values in the calculation above, where the t-test indicates whether the value of b is different from zero (0). The software tool SPSS 24 calculates the exact probability that the observed t-value would occur if the population value of b were zero (0). If this observed significance is less than 0.05, the result reflects a meaningful effect. In our case, this fully applies. For one t-value, the probability is 0.032, and for the other t-value it is 0.000 (rounded to three decimal places), so we can state that the probability of observing these t-values (or larger) if the population values of b were zero is less than 0.001. Therefore, the b-values are significantly different from zero. For b representing investments in tangible fixed assets, this result means that these investments significantly contribute ($p < 0.001$) to predicting increases in net sales revenue.

In the calculation, the bootstrap confidence interval indicates that the population value of b for tangible fixed assets (OOS) lies between 0.894 and 2.193. Because this interval does not include zero (0), we can conclude that a meaningful positive relationship exists in the population between investments in OOS and net sales revenue (ČPP). The significance associated with this confidence interval is $p = 0.012$, which is significant. The bootstrap procedure also recalculates the standard error, which changes from 0.271 to 0.338 – a small change. For the constant, the standard error is 9,981,459.46, while the bootstrap estimate of the standard error is 11,901,364.94. The difference is 1,919,905.54. Bootstrap confidence intervals and significance values are useful because they do not rely on assumptions about normality of the distribution or homoscedasticity (Field 2013). Figure 2 shows the distribution of correlation coefficients between the variables OOS and ČPP for all companies included in the sample.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
https://doi.org/10.9770/k7580642657

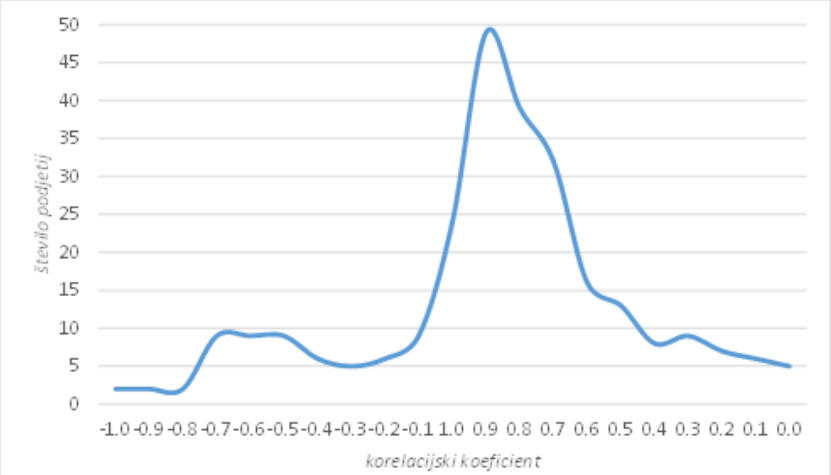


Figure 2. Distribution of correlation coefficients for the variables OOS and ČPP for all companies included in the sample for the period 2000–2017

Source: Own representation based on the calculation of correlation coefficients for the variables OOS and ČPP for 267 companies in the sample for the period 2000–2017.

Note: The ordinate (vertical) axis represents the number of companies, while the abscissa (horizontal) axis represents the correlation coefficients.

Based on the results presented above, we can confirm and accept our first research hypothesis H1: Strategic investments are the greatest driver of company growth.

4.2 Testing the Research Hypothesis H2 on the Impact of Increased Strategic Investments on Net Profit and Thus on Company Value

Let us examine how an increase in investments in tangible fixed assets affects the movement of net profit for the accounting period (NP) and, consequently, company value. In the case of this indicator, the predictive value of the regression coefficient b is completely lost. The returns on investments – measured by net profit for the accounting period – generated by the investments in tangible fixed assets by the companies in our sample during the period 2000 -2017 were practically negligible. If we take into account financial expenses for interest and other obligations (account 06402), we can understand why net profit for the accounting period was relatively modest or even negative (loss). In the period before the financial crisis in 2008, companies borrowed heavily to finance their investments, for which they had to pay interest to financial institutions, thereby reducing net profit.

Instead of net profit generated by strategic investments – in particular, investments in tangible fixed assets – being a source of increasing company value and, consequently, an important source of financing new investments, this did not happen after the mentioned crisis. Companies instead used profits (their accumulated earnings) for deleveraging. Therefore, for this examined period, we cannot claim or prove that profit generates value. In a given year, yes, it does, but it does not remain in the company as retained earnings; instead, it is used to repay principal on loans. It is true, however, that by reducing net financial debt, the companies' capital adequacy improves, and their equity relatively increases.

The graph in Figure 3 shows the movement of absolute average values of some of the most important economic categories (financial indicators), including financial expenses, for our sample population of companies over the period 2000–2017.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
https://doi.org/10.9770/k7580642657

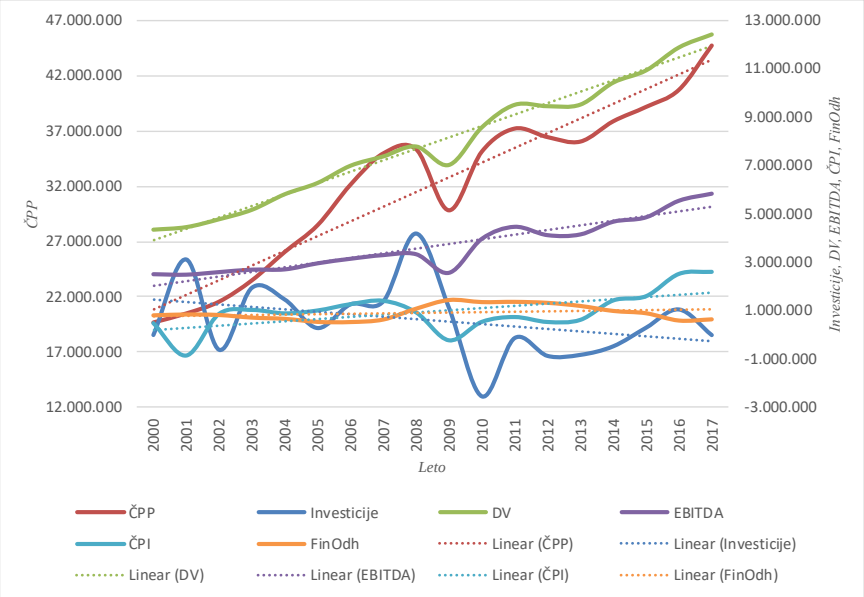


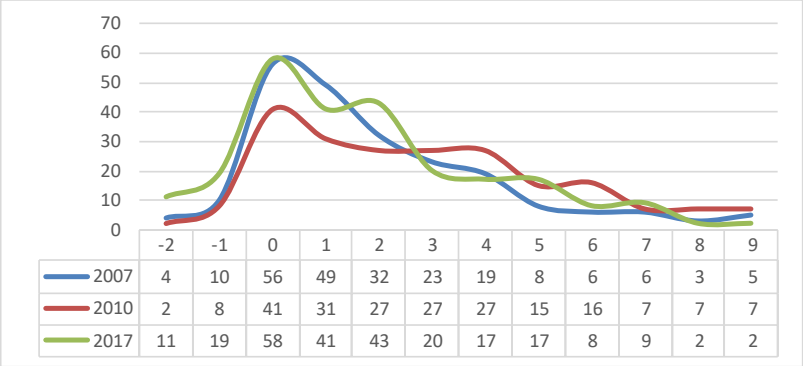
Figure 3. Financial indicators compared with the increase or decrease of tangible fixed assets for the sample companies (267) in the period 2000–2017.
Source: Own presentation based on data from the AJPES database for the period 2000–2017.
Legend: ČPP – net sales revenue; ČPI – net profit; Investicije – investments; FinOdh – financial expenses; DV – added value.

From Figure 3, it can be observed that during this 18-year period there was a specific phase marked by the global financial crisis and the worldwide economic recession, which lasted from 2008 to 2012. The dynamic growth of the mentioned categories – i.e., net sales revenue (ČPP), value added (DV), and net profit of the accounting period (ČPI) – halted in 2009; for the latter, the decline began already in 2008. The momentum of the rising trend in tangible fixed assets (OOS) continued despite the crisis until the end of 2009 (completion of pre-crisis investments). In 2010, there was a noticeable decline in the net book value of tangible fixed assets (reaching a low), as the net value of OOS decreased by approximately 6 %, and this level remained stable until 2015, when the average net value of OOS increased by about 3 % the following year, though it had not yet reached the pre-crisis average absolute level.

On the other hand, net sales revenue (ČPP) began to rise slightly after the significant drop in 2009, even during the recession period. The same applies to value added (DV). The greatest impact of the global financial crisis and economic recession was observed in the net profit of the accounting period (ČPI), which, as mentioned, began to decline sharply in 2008, increased slightly two years later, but remained at roughly half of its 2007 average value until 2013. From 2008 to 2013, the financial expenses for interest and other obligations, in absolute terms for the sample companies, even exceeded their total net profit.

In this part of the study, we are also interested in how financial expenses (interest) changed during the past period – data are available for the sample companies from 2005 to 2017 – in relation to financial leverage or company indebtedness. We examine the linear regression between the NFD/EBITDA ratio and financial expenses. In Figure 4, we first present the distribution curves of the NFD/EBITDA ratio for three time points: 2007 (pre-financial crisis), 2010 (during the financial crisis), and 2017 (post-financial crisis).

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
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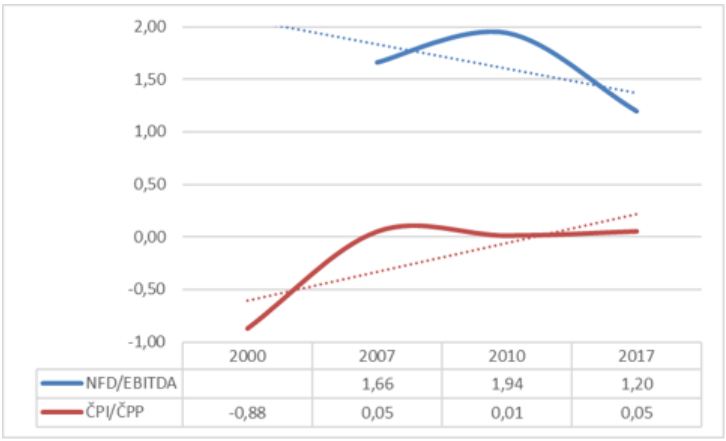


	-2	-1	0	1	2	3	4	5	6	7	8	9
2007	4	10	56	49	32	23	19	8	6	6	3	5
2010	2	8	41	31	27	27	27	15	16	7	7	7
2017	11	19	58	41	43	20	17	17	8	9	2	2

Figure 4. Distribution of the NFD/EBITDA ratio for the sample companies for the years 2007, 2010, and 2017
Source: Own presentation based on data from the AJPES database for the years 2007, 2010, and 2017.

From the graph in Figure 4, it can be seen that the red curve, which represents the normal distribution of the NFD/EBITDA ratio for the sample companies in 2010, is right-skewed (similarly to the other two curves), flatter (the other two curves are more compressed with higher peaks), and more stretched to the right, generally lying above the other two curves. This means that in the year of the last major financial crisis, absolutely more companies had relatively higher NFD/EBITDA ratios (more EBITDA was needed to cover net financial debt). This is indicated by the right side of the curve from the value 0. The left side of the same curve from 0, which lies below the other two curves, supports a similar conclusion. Companies in the sample that were not indebted – their NFD/EBITDA ratio was negative – either had more cash and cash equivalents, lower EBITDA, or both during the financial crisis. Thus, the NFD/EBITDA ratio below -2 was observed for more companies in 2007 and 2017 than in the crisis year. If we calculate for each company the regression coefficient between the NFD/EBITDA ratio and financial expenses for the period 2005–2017, we find no statistically significant relationship between them. Since net profit for the period is the main source for repaying principal on loans, we are finally interested in the relationship between the indebtedness of our sample companies and the profitability of their net sales revenue, which is graphically shown in Figure 5.

It is evident that after the financial crisis and economic recession, net sales profitability began to improve, reaching 5 % in 2017. This provided indebted companies with a source to repay their debt. This conclusion is further supported by the fact that, during the same period, the indebtedness of companies in our research sample began to decrease. The NFD/EBITDA ratio, which was almost 2 in 2010, fell to 1.20 by 2017. As mentioned, this is the average ratio of all 267 companies, calculated based on weighting by each company's net sales revenue.



	2000	2007	2010	2017
NFD/EBITDA		1,66	1,94	1,20
ČPI/ČPP	-0,88	0,05	0,01	0,05

Figure 5. Trends in indebtedness (NFD/EBITDA) and profitability of net sales revenue (ČPI/ČPP) for the sample companies during the period 2000 - 2017
Source: Own work based on data from the AJPES database for the period 2000 - 2017.
Based on the results presented above, we can confirm and accept our second research hypothesis H2: Strategic investments increase company value by generating profit

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
https://doi.org/10.9770/k7580642657

4.3 Testing the third research hypothesis H3 on the impact of increased strategic investments on productivity growth and improved financial performance of companies

In the graph in Figure 6, we show, for all companies in our research sample, the trends of two productivity indicators, expressed in value terms, namely net sales per employee (ČPP/Z) and value added per employee (DV/Z), for the period 2000–2017.

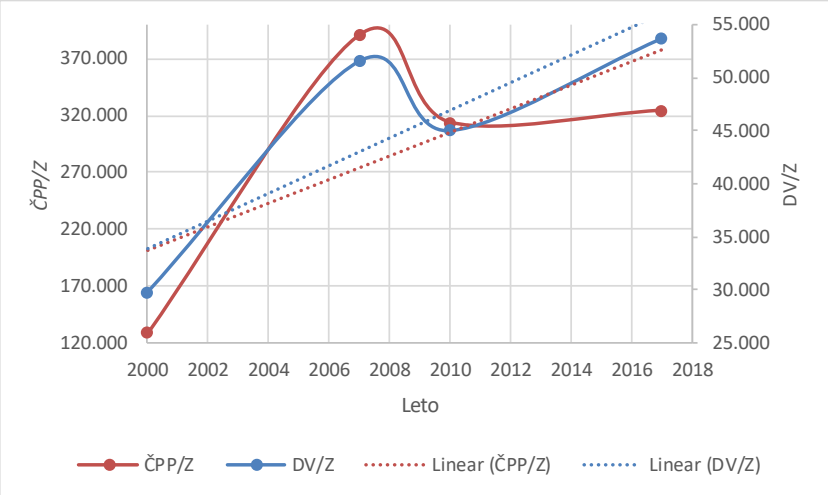


Figure 6. Trends in productivity (Net Sales per Employee – ČPP/Z; Value Added per Employee – DV/Z) for the sample companies in the period 2000 - 2017
Source: Own representation based on data from the AJPES database for the period 2000 - 2017.

Productivity increased sharply in the period from 2000 until the major financial crisis in 2008. The crisis caused a decline, but after the crisis, productivity began to rise again, especially productivity measured by value added per employee.

Figures 7 and 8 show the ratio between the value added of the 30 largest companies in the sample and the value added of the other companies in the sample over the past 18 years. Both graphs show that, every year except during the year of the last major financial crisis and economic recession (2009), the 30 largest companies in the sample collectively generated more value added than the remaining companies in the sample (such data were available for only 237 companies in the sample) and that after that year, the gap began to widen.

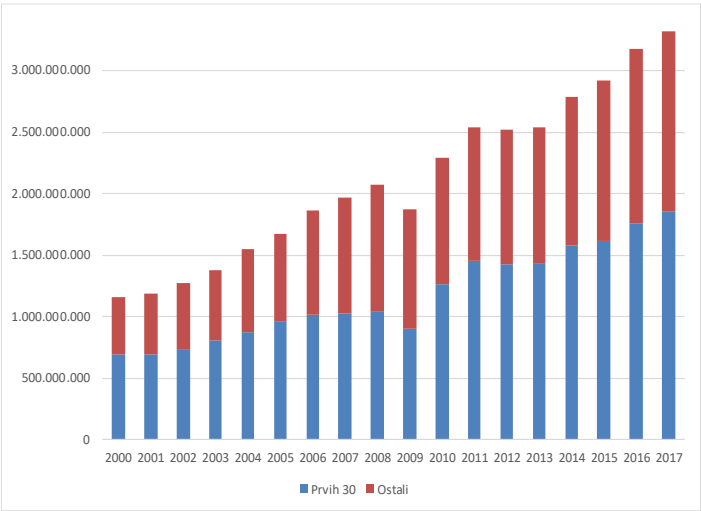


Figure 7. Dynamics of value added for the 30 largest sample companies in the period 2000 - 2017
Source: Own representation based on data from the AJPES database for the period 2000 - 2017.
Note: The ordinate (vertical) axis represents value added in euros, while the abscissa (horizontal) axis represents the 30 largest sample companies (blue) and the others in the sample (red).

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
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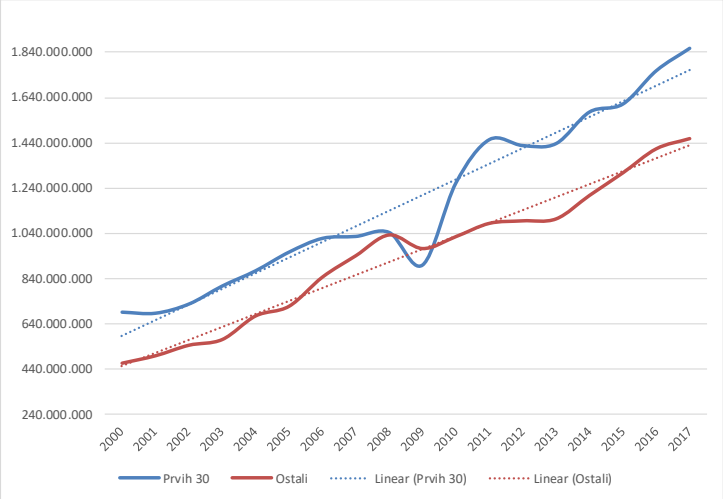


Figure 8. Dynamics of added value of the 30 largest sample companies in the period 2000 - 2017
Source: Own illustration based on data from the AJPES database for the period 2000 - 2017.

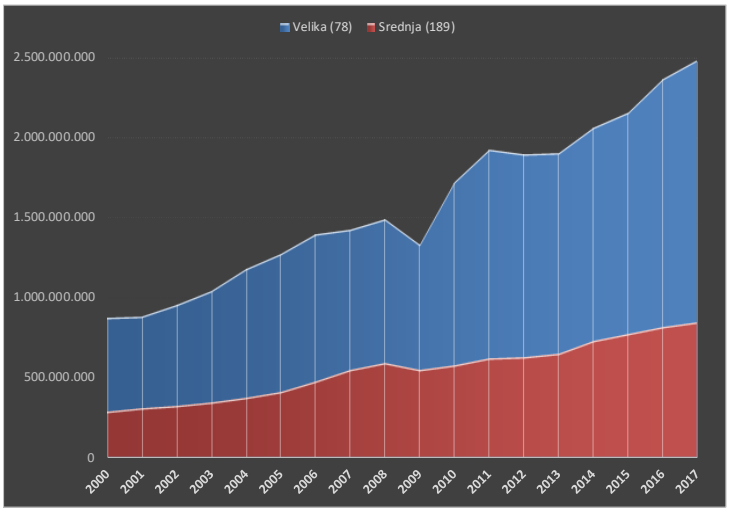


Figure 9. Dynamics of added value of large and medium-sized sample companies (267) in the period 2000 - 2017
Source: Own presentation based on data from the AJPES database for the period 2000 - 2017

Figure 9 above shows the ratio of added value generated over the past 18 years by large and medium-sized companies in our sample. From Figure 9, it can be seen that the 78 large companies created significantly more added value than the 189 medium-sized companies, but after 2009, at the start of economic recovery, the relative share of the latter gradually increases. Figure 9 shows how the financial crisis and economic recession affected the companies in our research sample and that, after these events, the added value per employee increased faster than net sales per employee, although by 2017 the companies had not yet reached pre-crisis levels.*Next, we examine the imp*act of strategic investments on the financial performance of companies. For this purpose, we calculated the correlation between investments in tangible fixed assets and the financial indicators presented in the theoretical part of this paper (Chapter 2.7). Based on our findings and statistical analyses, the graphical presentation in Figure 10 includes only those financial indicators that show a statistically strong or moderately strong correlation with strategic investments, i.e., investments in tangible fixed assets. From Figure 10, it can be seen that the correlation is strong with net sales, added value, and EBITDA, but weaker with net profit.

The impact of the independent variable, i.e., investment in tangible fixed assets, on the financial indicator, namely EBITDA, was found to be weak ($R^2 = 0.305$; $b_1 = 0.145$; Sig.: 0.02), while for net profit of the accounting period (ČPI) this impact was negligible ($R^2 = 0.025$). In the case of b for investments in tangible fixed assets, the result indicates that these investments significantly contribute ($p = 0.02$) to predicting an increase in EBITDA. An increase in tangible fixed assets by 1,000 € generates 145 € of operating cash flow. This, of course,

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
https://doi.org/10.9770/k7580642657

applies to a one-year period. The investment generates cash flow over its entire useful life, which certainly spans multiple years depending on the type of tangible fixed asset. This is not a very high return on productively invested assets when compared to the returns of otherwise riskier financial investments.

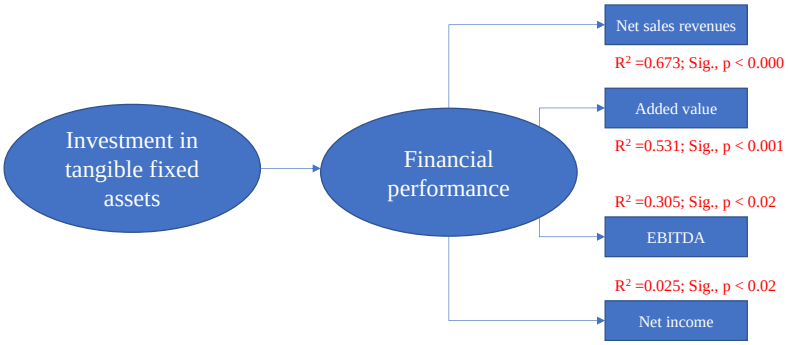


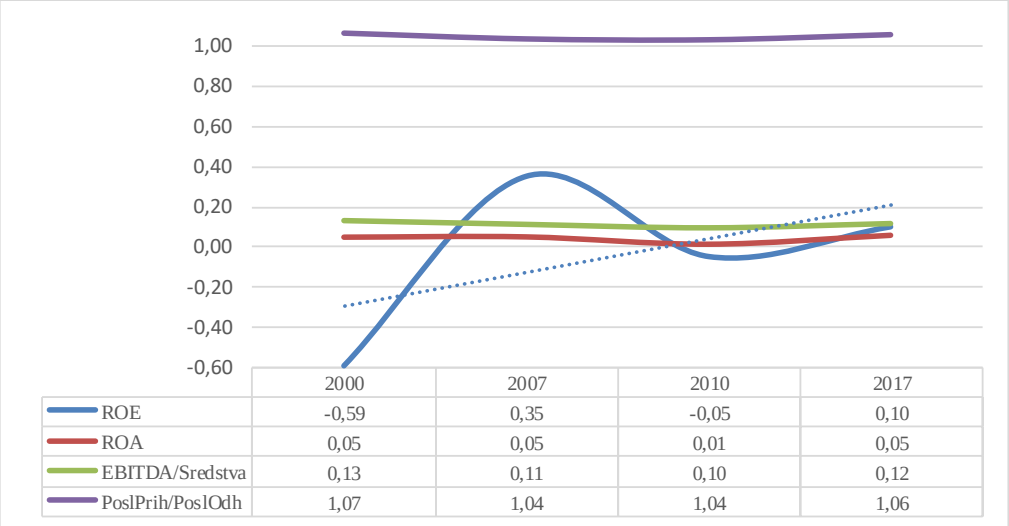
Figure 10. The impact of strategic investments (Tangible Fixed Assets) on improving financial business performance
Source: Own representation based on data from the AJPES database for the period 2000 - 2017 and statistical processing of data in SPSS 24

Since net profit, especially if not distributed to owners and retained in the company, increases equity and thus the value of the company, and can also serve as a main source for debt repayment, we are also interested in the relationship between the indebtedness of our sample companies and their profit margin over the entire research period. This is shown in Figure 11. The profit margin began to improve immediately after the financial crisis and economic recession, reaching 5 % in 2017. Companies with higher financial leverage generated funds for debt repayment. This is further supported by the observation that companies in our sample began reducing their indebtedness during the same period. The NFD/EBITDA ratio, which was almost 2 in 2010, decreased to 1.20 in 2017. As previously mentioned, this is a weighted average of all 267 companies, calculated using the net sales of each company as weights.

We are also interested in another indicator, which we want to include in a regression equation alongside net sales (ČPP). This is ROA, return on assets. We would expect that if net sales increased significantly due to investments in tangible fixed assets (their impact was more than two-thirds), then ROA should also have increased correspondingly. Efficient use of production assets should be reflected in higher ROA. This raises the question of whether tangible fixed assets were truly well-utilized (production running in three or four shifts?) and whether companies were able to fully meet customer demand. Linear regression did not show a strong relationship between ROA and ČPP (R^2 = 0.236; Sig.: 0.048). This indicates a weak correlation between the compared variables.

Similar findings apply to other financial indicators, such as return on equity (ROE), the ratio of EBITDA to total assets, and the efficiency indicator (Operating Revenue / Operating Expenses), for which we also calculated linear regression with net sales revenue. The trends of these indicators for our sample companies in the period 2000 - 2017 are graphically shown in Figure 11. In the graph in Figure 11, the blue curve, representing ROE, stands out the most. This indicator was very high in 2007 (0.35) before the financial crisis, then gradually declined until 2010, and only by 2017 did the equity of owners in our sample companies reach an average annual return of 10 %. When assessing the return on investments, it is necessary to consider their return from the perspective of all stakeholders who provided the financing. Since these include financial institutions, interest on borrowed loans is considered a form of return generated by the investments. This return does not remain with the companies or their owners, but it represents the return produced solely by the investments themselves.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
https://doi.org/10.9770/k7580642657



	2000	2007	2010	2017
ROE	-0,59	0,35	-0,05	0,10
ROA	0,05	0,05	0,01	0,05
EBITDA/Sredstva	0,13	0,11	0,10	0,12
PoslPrih/PoslOdh	1,07	1,04	1,04	1,06

Figure 11. Trends in profitability and efficiency indicators for the sample companies in the period 2000 – 2017
Source: Own illustration based on data from the AJPES database for the period 2000–2017.

Based on the results presented above, we can confirm and accept our third research hypothesis *H3: Strategic investments increase productivity and improve business performance.*

5 Conclusion

This paper has demonstrated, both conceptually and empirically, that growth is essential for the development of national economies as well as for the long-term viability of individual companies, and that strategic corporate investments – particularly investments in innovation – are the key drivers of this growth. Growth stimulated by strategic corporate investments contributes directly to increasing company value, primarily through profits retained within the company and reinvested in future development. Sustainable growth, however, can be achieved only when companies effectively manage the risks inherent in innovation and growth strategies.

In the theoretical part, drawing on a broad body of literature, we examined in detail the central concepts relevant to our study: strategic corporate investments, company growth, company value, and financial performance indicators. Special attention was devoted to the notion of strategic corporate investments, a relatively recent and still evolving construct that demands conceptual clarification. The literature reveals a diversity of definitions, with authors adopting broader or narrower perspectives and delineating the specific activities that fall within this category. Our contribution to the scholarly debate lies in the synthesis, harmonization, and updating of these approaches, which has allowed us to formulate the following definition: *Strategic corporate investments are expenditures in physical or human capital directed toward the creation of new value. They generally take the form of large-scale projects with long-term implications for company growth and development. Grounded in dynamic capabilities – such as innovation and research and development – they are designed to enhance competitiveness, expand operations, introduce new technologies (including artificial intelligence and green technologies), and strengthen strategic market positions. They are characterized by high risk, uncertain and often difficult-to-measure outcomes, and substantial long-term impact on business performance.*

The literature review also revealed a research gap: while the constructs of corporate growth, value creation, shareholder wealth, and reinvestment of returns have been studied individually, their interdependencies and causal linkages have not been systematically explored. To address this gap, the present study developed the *Strategic Corporate Investment Cycle – a novel conceptual model that explicates how strategic investments stimulate growth, how this growth translates into profitability, how profitability enhances company value, and how, ultimately, shareholder wealth is increased, and last but not least, how generated profit as retained earnings finances new strategic investments.* By framing strategic investments as the principal drivers of

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
https://doi.org/10.9770/k7580642657

sustainable growth and long-term value creation, the model advances our theoretical understanding of this domain.

The empirical analysis, based on a representative sample of large and medium-sized Slovenian companies and drawing on both primary and secondary data for the period 2000–2017, tested three research hypotheses:

- H1: Strategic investments are the main drivers of overall company growth – *Confirmed.*
- H2: Strategic investments increase company value through profit generation – *Confirmed.*
- H3: Strategic investments enhance productivity and improve business performance – *Confirmed.*

All three hypotheses were fully supported by rigorous statistical testing, thereby reinforcing the validity of the proposed model. The study concludes that strategic corporate investment decisions are among the most consequential financial choices faced by companies, with long-term implications for competitiveness and sustainability. When investment risks are adequately managed, such decisions not only secure profitable and sustainable growth but also reinforce the cycle of reinvestment – particularly in innovations. Technological and managerial knowledge emerge as the *spiritus agens* that propels the strategic corporate investments cycle, enabling companies to recognize the interdependence of knowledge, innovation, and growth, and to continually pursue new investment opportunities.

Finally, the study points toward several promising avenues for further research. Future studies could extend the analysis to larger international samples, employ longitudinal designs to uncover causal dynamics within the proposed model, and incorporate investment in human capital, and non-financial performance indicators that reflect the broader impact of strategic corporate investments. It would also be valuable to replicate the study with more recent data – covering the post-2018 period – to compare the findings with those presented here and to examine how new global economic and technological trends may influence the *strategic corporate investments cycle*.

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ENTREPRENEURSHIP AND REGIONAL ECONOMIC DYNAMICS: EVIDENCE FROM THE LIBEREC REGION (2002–2024) USING GRANGER CAUSALITY AND VAR MODELS

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Abstract. This study examines the correlation between entrepreneurship and regional economic success in the Liberec Region of the Czech Republic from 2002 to 2024. Utilizing yearly data on GDP per capita, unemployment, average income, investment, and new business formation, the study employs descriptive statistics, multiple regression, Granger causality tests, and Vector Autoregression (VAR) modeling. The results show that GDP per capita and average income have been steadily rising, whereas entrepreneurship has been following a cyclical pattern that is the opposite of unemployment trends. Regression research indicates that unemployment and income are the primary predictors of GDP, but the establishment of new firms exerts less short-term impact. Nonetheless, causality studies reveal a delayed, bidirectional link between entrepreneurship and GDP: economic progress fosters company creation, which, in turn, bolsters growth after a temporal lag. The results using VAR further support the idea that historical GDP values and lagged impacts of unemployment and entrepreneurship affect how regions expand over time. Entrepreneurship does not yield immediate benefits; instead, it fosters long-term growth by enhancing feedback loops within the regional economy. These findings indicate that policies designed to promote high-quality entrepreneurial activity, enhance labor market outcomes, and maintain investment are crucial for facilitating inclusive growth. This study contributes empirical data to the existing literature on entrepreneurship and regional development by concentrating on a specific Czech area, offering insights for policymakers in Central and Eastern Europe.

Keywords: entrepreneurship; regional economic development; Granger Causality; VAR, Liberec Region; Czech Republic

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1. Introduction

Entrepreneurship, which has its roots in economics, has evolved into an influential force shaping regional development, requiring an integrated analysis of various economic indicators. Entrepreneurship education enhances self-reliance and decision-making skills, with economic literacy programs significantly boosting financial knowledge and encouraging early entrepreneurial abilities (Manchidi, 2025). These skills interact with institutional factors, where informal elements like networking often have more influence than formal factors such as education or income (Razminienė & Tvaronavičienė, 2024; Šimelytė et al., 2024). In this environment, radical innovation stands out as a key driver of entrepreneurship and regional growth, though it remains underexplored in current research (Cabelkova et al., 2021; Audretsch et al., 2022). Accurately measuring

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innovative entrepreneurship by combining start-up activity and self-employment in high-tech industries is essential for assessing regional growth precisely (Piccinetti et al., 2023). Additionally, regional governments and universities serve not only as regulators but also as creators of knowledge, with investments in R&D directly boosting entrepreneurial activity (Aparicio et al., 2022). Building on these foundations, this study investigates new company formation in the Liberec Region and its effect on economic performance.

Since the early 2000s, there have been regional differences in wealth, productivity, and innovation capability in the Czech Republic. The Liberec Region, located in the country's north, is an especially fascinating case study for investigating the relationship between entrepreneurship and economic success. Historically known for its industry base, notably in textile and glass manufacture, the region has seen major restructuring since the country entered the European Union. Over the last two decades, Liberec has faced both possibilities and problems in developing new businesses, responding to global competition, and harmonizing with EU structural policy.

Research on the relationship between unemployment and new firm development in Poland and Slovakia reveals complicated patterns. According to studies, there is a favorable association between growing unemployment and an increase in new business registrations, notably in the service sector (Wosiek, 2021). This implies the existence of "necessity entrepreneurship" motivated by unemployment. However, the extent of this influence differs by geography and industry (Wosiek et al., 2022). In Slovakia, an examination of investment aid from 2002 to 2018 reveals that it was not properly targeted at disadvantaged regions, with 56% of investments flowing to places with below-average unemployment rates (Hvolkova & Klement, 2020). Furthermore, research in the Moravian-Silesian Region of Czechia indicates an inverse association between unemployment and economic indices such as GDP and gross value added, corroborating Okun's Law (Kalinová & Kroutlová, 2023). These findings emphasize the complicated relationship between unemployment, entrepreneurship, and regional economic growth.

This study seeks to address this gap by investigating the link between entrepreneurship and regional economic dynamics in the Liberec Region from 2002 to 2024. The methodology uses time series data on GDP per capita, average income, unemployment, and new firm formation to examine directionality and temporal correlations. Additionally, impulse response functions and variance decomposition are used to represent the propagation of shocks across variables. As a result, our work raises two significant research questions:

RQ1: How has the formation of new companies in the Liberec Region evolved between 2002 and 2024, and what is its relationship with key economic indicators such as GDP per capita, unemployment rate, average income, and investment rate?

RQ2: Does the activity of new company formation in the Liberec Region have a short-term or long-term impact on regional economic performance, and how do economic shocks influence this relationship?

By focusing on a single Czech region over more than two decades, this paper contributes to both the literature on regional entrepreneurship and the methodological advancement of causality-based econometric analysis in regional studies. The findings are expected to provide valuable insights not only for academic discourse but also for policymakers seeking to design evidence-based strategies that enhance entrepreneurship as a catalyst for regional development.

2. Literature Review

2.1 Entrepreneurship and Growth in the Area

Entrepreneurship has always been recognized as a vital catalyst for economic growth and structural transformation at both national and regional scales. Evidence from Zambia indicates that institutional frameworks, such as the small firm’s regime, frequently fail to achieve their intended objectives, underscoring the necessity for more customized support mechanisms (Phiri, 2023). Historical analyses indicate that social entrepreneurship has operated as a collective movement, disseminating innovations in welfare, education, and healthcare in Northeast England during the 19th and early 20th centuries, thereby providing benchmarks for comprehending the contemporary social economy (Maclean et al., 2024). Scholars contend that, beyond liberal

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models, even planned economies may have institutional incentives for innovation and entrepreneurship, hence contesting the traditional Austrian School view on efficiency (Nieto, 2022). Critiques of the gig economy emphasize that framing insecure work as entrepreneurship-exemplified by Uber's model-obscures inequities and perpetuates neoliberal labor market dynamics (Ahsan, 2020). These works collectively illustrate the varied and occasionally contentious role of entrepreneurship in promoting economic and social progress.

2.2 Circular Economy and Entrepreneurial Business Models

The use of circular economy (CE) ideas in company models has been an expanding focus within entrepreneurship studies. In Spain, rural CE enterprises have slower development yet greater survival rates and profitability in comparison to their urban counterparts, indicating that the environment significantly influences outcomes (Magdalena et al., 2025). Other research shows that local and international companies use CE principles in diverse ways, and that this varies a lot from one industry to the next (Silva et al., 2024). Some businesses, including the agri-food sector, have gotten better at reporting on corporate sustainability, but there are still big gaps in meeting EU regulatory standards (Falkenberg et al., 2023). Transitioning to circular service-based models is further hampered by obstacles in reverse supply chain architecture and market identification, complicating profitability (van Loon & Van Wassenhove, 2020). Sectoral studies provide further insights: Slovak textile companies exhibit favorable revenue trends but encounter legal and institutional obstacles (Hanulakova et al., 2021), whereas greentech enterprises utilizing food waste yield various socio-economic advantages despite inconsistent results (Scaffidi, 2022).

2.3 Digital Economy, New Ideas, and Starting a Business

The digital economy has become a key component in determining entrepreneurship, innovation, and competitiveness. In China, digitalization cuts down on carbon emissions by making better use of resources. However, significant state interference makes these advantages weaker (Chen, 2022). Firm-level research indicates that digitalization promotes green innovation by reinforcing internal controls and long-term investment strategies, especially in companies with significant management ownership (Liu et al., 2024). The digital revolution also helps save energy, mostly through new ideas from entrepreneurs. However, the consequences are different in different places, with periphery cities getting less benefit (Wang & Shao, 2023). More in-depth studies show that digital ecosystems and cooperation between government, business, and academia are necessary for long-term competitiveness (He et al., 2024). Simultaneously, digital transformation has demonstrated the capacity to foster disruptive innovation, with entrepreneurship serving as a moderating influence; however, this correlation is less pronounced in state-owned firms (Wu & Li, 2024).

2.4 The relationship between entrepreneurship, law, and institutions

Legal systems and institutional frameworks have a big impact on how well entrepreneurs do. In the developing space economy, businesses intentionally highlight their social advantages while minimizing dangers, demonstrating how legitimacy theory elucidates selective corporate disclosures (Di Tullio & Rea, 2024). At the regulatory level, disparate approaches to megaconstellations, private space stations, and orbital services underscore enduring deficiencies in space law and governance (Daniels-Dawes et al., 2024). Similar dynamics manifest in conventional industries: global oilfield service companies are adopting Industry 4.0 innovations, whereas Russian enterprises are hindered by restricted investment, limited technological scope, and inadequate state support, highlighting the significance of regulatory and institutional contexts (Razmanova & Andrukhova, 2020). These results illustrate that entrepreneurship is inextricably linked to its institutional and legal frameworks, which significantly influence firm-level tactics and sectoral results.

2.5 The Gig Economy and New Types of Business Ownership

The emergence of the gig economy has sparked fresh discussions on the definition of entrepreneurship in modern labor markets. Bibliometric evaluations delineate the disjointed nature of research in this domain, highlighting clusters related to self-employment, digitalization, and platform work, while emphasizing that the pivotal role of gig workers is still inadequately examined (Silva & Moreira, 2022). In addition, critical studies say that gig platforms like Uber purposely position unstable jobs as entrepreneurship, which hurts workers' rights and makes inequality worse (Ahsan, 2020). These viewpoints indicate that the gig economy broadens the parameters of entrepreneurial dialogue while concurrently posing essential inquiries on equality, regulation, and the genuine liberty of workers.

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2.6 Gap in Research

The research elucidates the multifaceted interactions between entrepreneurship and regional development, transitions to a circular economy, digital innovation, institutional frameworks, and labor markets. These studies collectively emphasize the significance of entrepreneurship as a catalyst for economic development and structural transformation; nonetheless, notable gaps persist. First, the majority of empirical studies have concentrated on national or cross-national assessments, with little focus on regional dynamics, particularly in Central and Eastern Europe. Second, while circular economy and digitalization are often associated with entrepreneurship, their impacts on conventional regional growth metrics such as GDP per capita, unemployment, and investment are seldom examined within a cohesive econometric framework. Third, a significant portion of the current literature depends on descriptive or qualitative data, with a limited number of studies employing causality-based econometric techniques (e.g., Granger causality, VAR models) to elucidate dynamic feedback processes between entrepreneurship and economic results. Lastly, the Czech Republic is still not well-represented in this research, with Prague and other big cities getting more attention than less important areas.

In addition, although recent scholarship has advanced hybrid decision-support models, fuzzy logic approaches, and algorithmic personalization in areas such as tourism, healthcare, and media ecosystems (Gavurova et al., 2023–2025), their direct application to regional entrepreneurship and growth remains underexplored. Most of these contributions emphasize sectoral or institutional contexts, without explicitly linking such tools to entrepreneurial ecosystems or regional development trajectories. Lastly, the Czech Republic remains insufficiently represented in this body of work, with Prague and other metropolitan centers receiving more scholarly attention than peripheral regions such as Liberec.

This study fills these gaps by looking at the Liberec Region from 2002 to 2024 using a mix of descriptive analysis, regression modeling, and dynamic econometric methods. Concentrating on a specific region over a span of two decades offers innovative perspectives on the directional and temporal dynamics of the link among entrepreneurship, GDP per capita, unemployment, and investment. In doing so, it adds to the larger body of work on regional entrepreneurship and gives policymakers who want to improve entrepreneurial ecosystems in areas that haven't been researched as much evidence-based advice.

2.7 Decision-Support Systems and Digital Transformation

Recent scholarship has increasingly emphasized the integration of digital transformation, decision-support systems, and information technologies across diverse domains of economic and social development. Gavurova et al. (2025) highlight the socio-economic implications of digital transformation in tourism, proposing hybrid decision-support models to improve sectoral efficiency. Complementary research extends these models to socially sensitive contexts, such as travel planning for people with disabilities, where fuzzy set theory enables greater inclusivity in decision-making (Gavurova & Polishchuk, 2025). The role of algorithmic personalization and digital media literacy has also been scrutinized, revealing persistent knowledge gaps in adapting individuals and institutions to rapidly evolving information environments (Moravec et al., 2025). Within healthcare, scholars examine both the managerial and evaluative dimensions of information technology integration (Smolanka et al., 2024; Chilunjika, Uwizeyimana, 2024) and the development of intellectual models to manage patient trust in primary care institutions (Gavurova, Smolanka & Polishchuk, 2024). Parallel efforts address the assessment of automated news content in relation to demographic structures, underscoring the broader relevance of information-analytical systems for media literacy and public communication (Gavurova et al., 2024). At the same time, contributions by Skare, Gavurova, and Polishchuk (2023) underscore the importance of large-scale decision-making models for financing tourism infrastructure and start-up ventures through crowdfunding, thereby linking entrepreneurial financing to regional development priorities. In the healthcare domain, fuzzy decision-support approaches have been employed for the evaluation and prioritization of competing projects, further demonstrating the adaptability of such methods across sectors (Gavurova et al., 2023).

Collectively, these studies illustrate the growing relevance of fuzzy logic, hybrid decision-support systems, and algorithmic personalization in both public and private sector decision-making. They emphasize how digital transformation and information integration reshape entrepreneurship, tourism, healthcare, and media

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2025 Volume 13 Number 2 (December)
https://doi.org/10.9770/n5249698324

ecosystems, while highlighting the need for adaptive models that account for uncertainty, inclusivity, and dynamic institutional contexts.

3. Methodology

This study employs a quantitative research design to analyze the dynamics of new company formation in the Liberec Region and its relationship with key economic indicators over the period 2002–2024. The methodological framework integrates descriptive statistics, econometric modeling, and time-series analysis to address the two research questions. Data were obtained from the Czech Statistical Office and regional economic reports, ensuring consistency and accuracy across the study period. The dataset includes annual observations for GDP per capita (CZK), unemployment rate (%), average income (CZK), investment rate (%), and the number of newly established companies in the Liberec Region. All statistical and econometric analyses were conducted using Python (pandas, statsmodels, matplotlib) for data processing and visualization, ensuring reproducibility. The investment rate has two missing values for 2023 and 2024 due to unavailability in official records, which were kept as NaN in the dataset.

For Research Question 1, the analysis uses absolute values of each variable to explore long-term trends and cross-variable relationships. For Research Question 2, GDP per capita is converted into annual growth rates, while unemployment and new company formation are differenced to achieve stationarity based on Augmented Dickey–Fuller (ADF) test results. The new company formation variable required a second difference before achieving stationarity.

The methodological process follows four main stages. At first, descriptive and correlation analyses were used to visualize trends and examine preliminary associations between new company formation and economic indicators. Then these results will be presented in the form of line graphs for the individual variables and a heatmap for the correlation matrix.

Secondly, Multiple regression models were used to assess the statistical significance and magnitude of relationships for RQ1. To investigate the relationship between GDP per capita and key economic indicators in the Liberec Region, Ordinary Least Squares (OLS) regression models were estimated. This approach quantifies the linear association between the dependent variable (GDP per capita) and selected explanatory variables, allowing for the assessment of individual and joint effects. There will be three regression models made, at first combining all, and later combining two different variables each: Equation 1 shows the models 1:

$$GDP_t = \beta_0 + \beta_1 N_t + \beta_2 U_t + \beta_3 A_t + \beta_4 I_t + \varepsilon_t \quad (1)$$

Where, GDP_t is the Gross Domestic Product per capita at the time t, β_0 to $\beta_1$represent the estimated coefficients for the independent variables, N_t, U_t, A_t, and I_t are the New companies, Unemployment, Average Income, Investment rate in the region at time t. ε_t is the error term capturing unexplained variation.

To assess multicollinearity among the independent variables, the Variance Inflation Factor (VIF) was calculated, ensuring that the regression estimates were not distorted by high intercorrelations. The VIF can be calculated by using the equation:

$$VIF_i = \frac{1}{1 - R_i^2} \quad (2)$$

Where R_i^2 is obtained by regressing the i-th independent variable on all remaining predictors. Values above the conventional threshold (typically 10) indicate potential multicollinearity concerns.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
https://doi.org/10.9770/n5249698324

Model 1: GDP per capita ~ New companies + Unemployment: The first regression model was formulated to examine the relationship between GDP per capita (GDP_t) and two key predictors-new company formation (N) and unemployment rate (U)in the Liberec Region, expressed as:

$$GDP_t = \beta_0 + \beta_1 N_t + \beta_2 U_t + \varepsilon_t \quad (3)$$

Model 2: GDP per capita ~ New companies + Investment rate: The second regression model was formulated to examine the relationship between GDP per capita (GDP_t) and two key predictors-new company formation (N) and investment rate (I) in the Liberec Region. The model is expressed as:

$$GDP_t = \beta_0 + \beta_1 N_t + \beta_2 I_t + \varepsilon_t \quad (4)$$

Thirdly, stationarity and VAR modeling-ADF tests were conducted for each variable, succeeded by differencing where required. A Vector Autoregression (VAR) model was then estimated for RQ2 to capture interdependencies between variables, and Granger causality tests were applied to assess the predictive relationships between new company formation, GDP per capita, and unemployment.

Next, The Augmented Dickey-Fuller (ADF) test was applied to examine the presence of unit roots. The test was specified as:

$$\Delta S_t^{(d)} = \alpha + \beta t + \gamma\, S_{t-1}^{(d)} + \sum_{i=1}^{p} \delta_i\, \Delta S_{t-i}^{(d)} + \varepsilon_t \quad (5)$$

where S_t is the original series (GDP per capita, unemployment, new companies). $S_t^{(d)} = \Delta S_t$ is the series after applying d differences to achieve (or test for) staionarity. For example, d=1 for the first dfferences; d=2 for second differences. $\Delta S_t^{(d)} = S_t^{(d)} - S_{t-1}^{(d)}$. α is the intercept, βt is an optional time trend, γ is the unit-root coefficient, and δ_i control serial correlation upto lag p. ε_t is the white-noise error term. Here the null hypothesis written as H_0: $\gamma = 0$ (unit root; $S_t^{(d)}$is non-stationary) and the alternative hypotheis is, H_a: $\gamma < 0$ (stationary).

Granger Causality Analysis is used to investigate potential directional relationships between GDP per capita (GDP_t), new company formation (N), and unemployment rate (U) in the Liberec Region, the Granger causality test was applied. The test determines whether past values of one time series contain predictive information about another time series, beyond the information already contained in its own past values. The general form of the Granger causality model can be expressed as:

$$Y_t = \alpha_0 + \sum_{i=1}^{p} \alpha_i\, Y_{t-i} + \sum_{i=1}^{p} \beta_i\, X_{t-i} + \epsilon_t \quad (6)$$

where Y_t and X_t are stationary time series, p is the number of lags, α_i and β_i are parameters to be estimated, and ϵ_t is the error term. If the coefficients β_i are jointly statistically significant, X is said to "Granger-cause" Y. Optimal lag lengths (p) were selected to capture short- and medium-term dynamics, with tests performed for one, two, and three lags. The analysis reported both F-statistics and Chi-square statistics, with significance determined at the 5% level based on Chi-square p-values. The test outcomes provided evidence on whether GDP per capita, new company formation, and unemployment rates have predictive relationships over different time horizons.

Finally, Impulse Response Functions (IRFs)-to evaluate the short-term and long-term impact of economic shocks (e.g., new company formation shocks) on GDP growth and unemployment. This mixed approach enables both a macro-level understanding of the evolution of new company formation in the Liberec Region and a dynamic analysis of how shocks propagate through the regional economy.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
https://doi.org/10.9770/n5249698324

4. Results

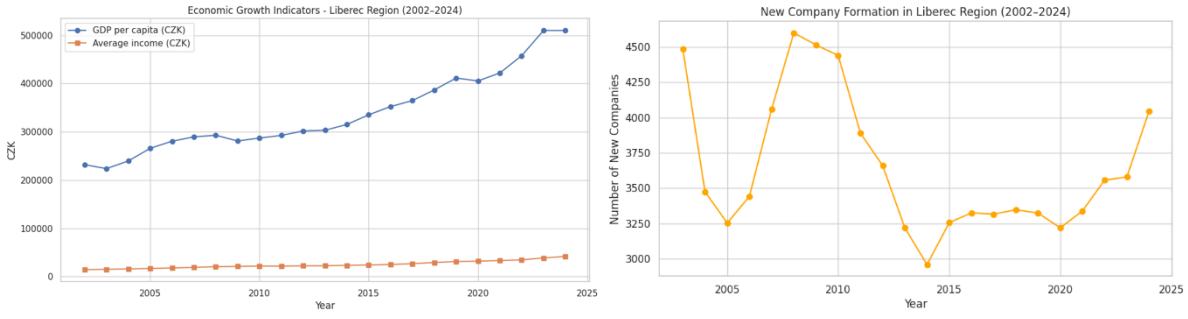
For the first research question, the descriptive statistics from Table 1 show a clear pathway of understanding regarding the dataset contains the variables GDP per capita, unemployment, average income, the number of new companies, and the investment rate in the Liberec region in the Czech Republic from the period of 2002 to 2024. Out of the total 23 yearly observations, the New companies and the investment rate from the Liberac region lack one and two observations, respectively. From the data, it's clearly visible that there is a strong expansion in the GDP per capita, which has risen from 223,734 to 510,000 CZK (≈+128% span). In the same way, the average income climbed from 14,113 to 41,549 CZK/month (≈+195%), and the investment rate from 41,275 to 114,868 CZK (≈+178%). The GDP, income, and investment show right-skewed growth, and the labor market shows sizable cyclical swings. And also, the Entrepreneurial activity is steadier in the region. In the bottom line, the Liberec regions exhibit sustained economic growth in output, incomes, and investment from 2002–2024, volatile unemployment, and a moderately stable pace of new firm creation.

Table 1. Descriptive Statistics of Key Economic Indicators for the Czech Republic (2002-2024)

	Count	mean	std	min	25%	50%	75%	max
GDP_per_capita	23	337383.87	83035.91	223734	284064	303186	396122	510000
Unemployment	23	6.59	2.54	2.95	4.015	6.5	8.68	11.1
Avg_income	23	24603.83	7550.08	14113	19699	22424	30056.5	41549
New_companies	22	3650.05	493.31	2959	3318	3458.5	4006	4599
Investment_rate	21	73245	19876.26	41275	57942	68482	78962	114868

Source: Own Research

From 2002 to 2024, the Liberec Region shows steady growth in GDP per capita, with a notable acceleration after 2018, reaching nearly 500,000 CZK, while average income increases more slowly. This widening gap between total output and household income highlights growing inequality. The formation of new companies follows a cyclical pattern: an initial decline, a peak from 2008 to 2010, contraction until 2014, then stabilization and a rebound after 2021. This pattern inversely mirrors unemployment rates; higher joblessness coincides with lower startup entry rates, while a decrease in unemployment from 2014 to 2019 aligns with modest growth in startups and a partial recovery after 2020. The investment rate is on an upward trend, with significant increases from 2018 to 2020, remaining at historically high levels that support capital-driven growth. The data indicate that strong investment and improved labor market conditions drive GDP growth, that entrepreneurial activity responds to macroeconomic shocks with a delay, and that the faster rise in production compared to incomes raises concerns about the inclusiveness of recent development (Figure 1).



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2025 Volume 13 Number 2 (December)
https://doi.org/10.9770/n5249698324

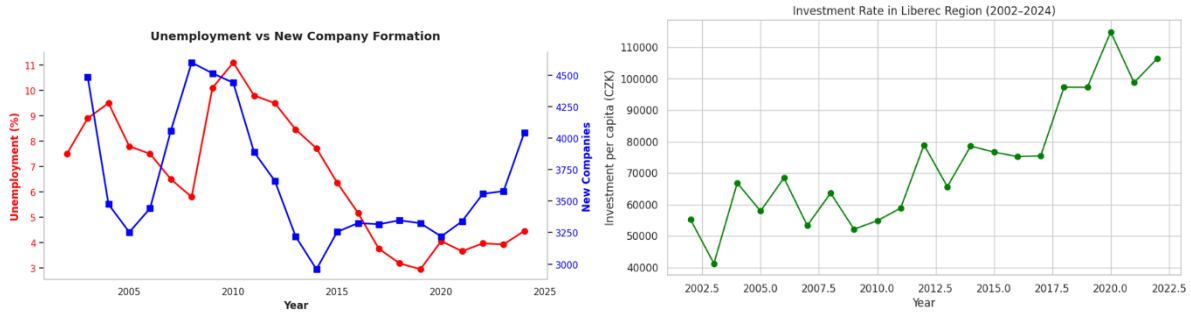


Figure 1. Economic Dynamics in the Liberec Region (2002–2024)-GDP per capita & average income, new company formation, unemployment vs. new companies, and investment rate per capita.
Source: Own Research

The correlation study for the Liberec Region from 2002 to 2024, as the in Figure 2, shows a steady pattern of economic interdependence. GDP per capita, average income, and investment rates are all strongly and positively linked, indicating that periods of rapid economic growth are usually accompanied by rising wages and increased capital investment. Conversely, unemployment has a notable negative relationship with both GDP per capita and average income, demonstrating that improvements in economic performance are closely tied to reductions in joblessness. Interestingly, new firm formation shows only a small negative correlation with GDP per capita and income, but a slight positive link with unemployment, suggesting that entrepreneurial activity may slightly rise during times of labor market slack. Additionally, the investment rate is significantly negatively correlated with new company formation, implying that higher capital flows don't always coincide with increases in entrepreneurial entries, highlighting different factors that drive investment and firm growth.

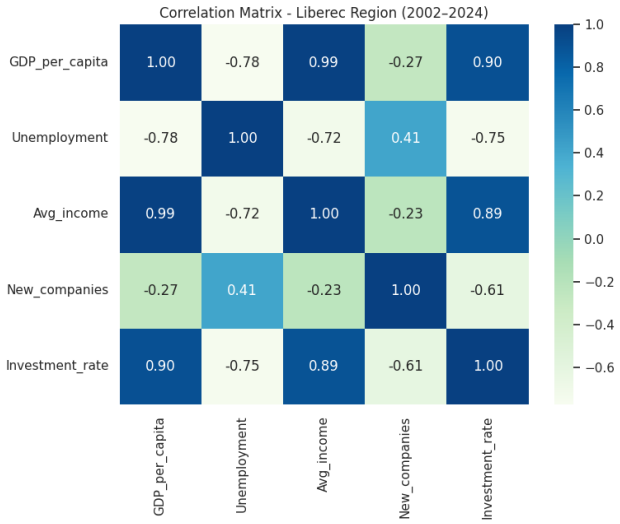


Figure 2. Correlation Matrix of Key Economic Indicators - Liberec Region (2002-2024)
Source: Own Research

Regression Modeling: The OLS regression findings from Table 2 show very good explanatory power, with an R-squared of 0.987, implying that the selected variables account for over 99% of the variation in GDP per capita in the Liberec Region. Average income has a strong positive correlation with GDP per capita ($\beta = 9.26$, $p < 0.001$), indicating that income increase is a vital factor driving regional economic progress. Unemployment has a substantial negative connection ($\beta = -4482.44$, $p = 0.001$), indicating an adverse correlation between labor market performance and economic production. However, the coefficients for new firm formation and investment rate are statistically negligible, implying that their direct effects on GDP per capita are weak in this formulation. The large condition number (1.24×10^6) indicates considerable multicollinearity, most likely due to close correlations between average income, investment rate, and GDP per capita. Individual coefficient magnitudes should be interpreted with caution.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
https://doi.org/10.9770/n5249698324

Table 2. OLS Regression Estimating the Determinants of GDP per Capita in the Liberec Region (2002-2024)

Dep. Variable:		GDP_per_capita		R-squared:		0.987
Model:		OLS		Adj. R-squared:		0.984
Method:		Least Squares		F-statistic:		290.7
No. Observations:		20		Prob (F-statistic):		5.16E-14
Df Residuals:		15		Log-Likelihood:		-205.6
Df Model:		4		AIC:		421.2
Covariance Type:		nonrobust		BIC:		426.2
	coef	std err	t	P>|t|	[0.025	0.975]
const	1.59E+05	2.82E+04	5.635	0	9.87E+04	2.19E+05
New_companies	-5.1853	5.041	-1.029	0.32	-15.93	5.559
Unemployment	-4482.4407	1152.716	-3.889	0.001	-6939.397	-2025.484
Avg_income	9.2626	0.81	11.442	0	7.537	10.988
Investment_rate	-0.0327	0.264	-0.124	0.903	-0.594	0.529
Omnibus:		5.937		Durbin-Watson:		1.313
Prob(Omnibus):		0.051		Jarque-Bera (JB):		3.66
Skew:		0.98		Prob(JB):		0.16
Kurtosis:		3.742		Cond. No.		1.24E+06
Notes: [1] Standard Errors assume that the covariance matrix of the errors is correctly specified. [2] The condition number is large, 1.24e+06. This might indicate that there are strong multicollinearity or other numerical problems.						

Source: Own Research

Variance Inflation Factor (VIF): The Variance Inflation Factor (VIF) results from Table 3 show extreme multicollinearity among the independent variables, with all VIF values significantly higher than the usually recognized threshold of 10. The average income (VIF = 116.06) and investment rate (VIF ≈ 82.94) exhibit exceptional collinearity, showing significant duplication in the information they give, possibly due to their strong correlation with GDP per capita and each other. New firm creation (VIF = 45.82) and unemployment (VIF ≈ 15.42) show substantial multicollinearity, but to a lower level. Such exaggerated VIF values indicate that coefficient estimates may be unstable and susceptible to minor changes in the model, distorting statistical significance and interpretability. To address this issue, variable selection, transformation, or regularization procedures may be required to ensure more trustworthy inference.

Table 3. Variance Inflation Factor (VIF) for Independent Variables in the GDP per Capita Model

Variable	VIF
New companies	45.81772
Unemployment	15.417931
Avg_income	116.059724
Investment_rate	82.944315

Source: Own Research

Model 1: GDP per capita ~ New companies + Unemployment: Model 1 accounts for 69.6% of the variation in GDP per capita ($R^2 = 0.696$), with an adjusted R^2 of 0.661, indicating a reasonable match. Unemployment is a significant predictor ($p < 0.001$) with a big negative coefficient (−19,190), suggesting that more unemployment leads to lower GDP per capita. New firm creation has a negative coefficient (−13.23) but is statistically insignificant ($p = 0.495$), indicating no direct impact on GDP per capita in this formulation. The comparatively low Durbin-Watson value (0.433) suggests that the residuals may have positive autocorrelation, which might compromise the dependability of standard errors. Overall, the model identifies unemployment as a major driver of GDP per capita in the Liberec region, whereas new firm creation appears to have a less immediate influence (Table 4).

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
https://doi.org/10.9770/n5249698324

Table 4. OLS Regression Results for GDP per Capita on New Company Formation and Unemployment

Dep. Variable:		GDP_per_capita		R-squared:		0.696
Model:		OLS		Adj. R-squared:		0.661
Method:		Least Squares		F-statistic:		19.49
No. Observations:		20		Prob (F-statistic):		3.99E-05
Df Residuals:		17		Log-Likelihood:		-237.31
Df Model:		2		AIC:		480.6
Covariance Type:		nonrobust		BIC:		483.6
	coef	std err	t	P>|t|	[0.025	0.975]
const	5.04E+05	6.20E+04	8.127	0	3.73E+05	6.35E+05
New_companies	-13.2335	18.994	-0.697	0.495	-53.308	26.841
Unemployment	-1.92E+04	3719.349	-5.161	0	-2.70E+04	-1.13E+04
Omnibus:		0.927		Durbin-Watson:		0.433
Prob(Omnibus):		0.629		Jarque-Bera (JB):		0.896
Skew:		0.402		Prob(JB):		0.639
Kurtosis:		2.346		Cond. No.		2.72E+04

Notes: [1] Standard Errors assume that the covariance matrix of the errors is correctly specified. [2] The condition number is large, 2.72e+04. This might indicate that there are strong multicollinearity or other numerical problems. Unemployment shows a significant negative association with GDP per capita, while new company formation is not statistically significant in this model.

Source: Own Research

Model 2: GDP per capita ~ New companies + Investment rate: Model 2 shows a strong explanatory power, with an R^2 of 0.828 and an adjusted R^2 of 0.808, indicating that around 80% of the variation in GDP per capita is explained by new company formation and investment rate. The investment rate emerges as a highly significant predictor ($p < 0.001$) with a positive coefficient (3.175), suggesting that higher investment levels are strongly associated with increases in GDP per capita. In contrast, the effect of new company formation remains statistically insignificant ($p = 0.296$) despite a positive coefficient (17.30), indicating that its direct contribution to GDP per capita is less clear in this model. The Durbin-Watson statistic of 2.097 suggests no major autocorrelation concerns, and residual diagnostics indicate no severe normality issues. Overall, the model underscores the pivotal role of investment rate in driving regional economic growth, while the impact of new company formation appears less immediate (Table 5).

Table 5. OLS Regression Results for GDP per Capita on New Company Formation and Investment Rate

Dep. Variable:		GDP_per_capita		R-squared:		0.828
Model:		OLS		Adj. R-squared:		0.808
Method:		Least Squares		F-statistic:		40.88
No. Observations:		20		Prob (F-statistic):		3.20E-07
Df Residuals:		17		Log-Likelihood:		-231.64
Df Model:		2		AIC:		469.3
Covariance Type:		nonrobust		BIC:		472.3
	coef	std err	t	P>|t|	[0.025	0.975]
const	2.71E+04	8.08E+04	0.336	0.741	-1.43E+05	1.98E+05
New_companies	17.2989	16.032	1.079	0.296	-16.526	51.123
Investment_rate	3.175	0.41	7.744	0	2.31	4.04
Omnibus:		1.853		Durbin-Watson:		2.097
Prob(Omnibus):		0.396		Jarque-Bera (JB):		1.395
Skew:		-0.624		Prob(JB):		0.498
Kurtosis:		2.659		Cond. No.		9.87E+05

Notes: [1] Standard Errors assume that the covariance matrix of the errors is correctly specified. [2] The condition number is large, 9.87e+05. This might indicate that there are strong multicollinearity or other numerical problems. Investment rate is a significant positive driver of GDP per capita, whereas new company formation does not show a statistically significant effect in this model.

Source: Own Research

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2025 Volume 13 Number 2 (December)
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Pairwise Relationships with Regression Lines: These scatterplots from Figure 3 below show the pairwise correlations between GDP per capita and major economic indicators in the Liberec Region from 2002 to 2024. The first figure (New Companies versus GDP per Capita) shows a slightly negative slope, showing that greater rates of new company creation are weakly related to lower GDP per capita; however, the association looks minor and is undoubtedly impacted by external variables. The second plot (Unemployment versus GDP per Capita) shows a strong negative association, with rises in unemployment resulting in considerable drops in GDP per capita, showing the severe economic consequences of joblessness. The final plot (Investment Rate versus GDP per Capita) shows a significant positive connection, indicating that greater investment rates are substantially associated with higher GDP per capita, emphasizing the importance of capital investment in regional economic growth. Together, these visual patterns correspond to regression results in which unemployment has a substantial negative influence, investment rates have a strong positive impact, and new firm creation has a smaller direct effect on GDP per capita.

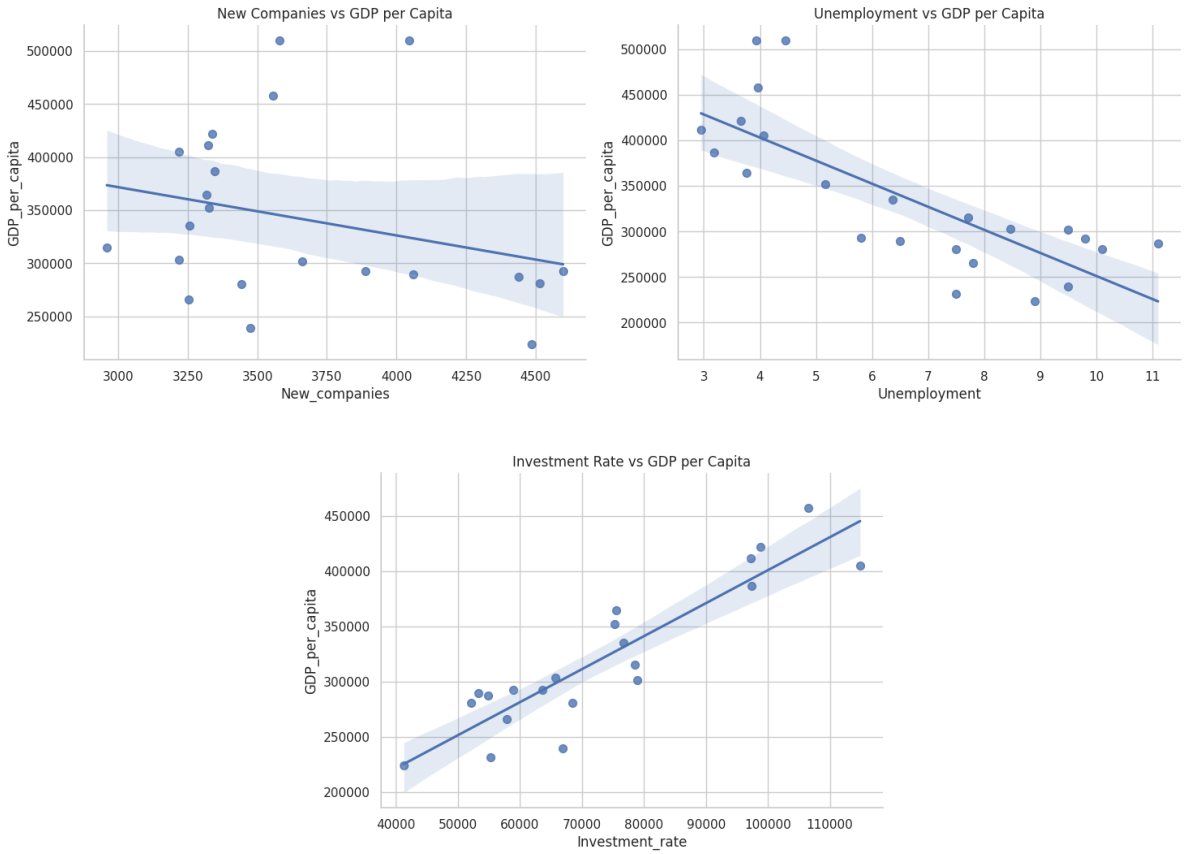


Figure 3. Scatter Plots - Relationships Between GDP per Capita and Key Economic Indicators in the Liberec Region (2002-2024)
Source: Own Research

For the second research question, the analysis begins with preparing the time series data for GDP per capita (expressed as a growth rate percentage), unemployment rate, and new company formation for econometric modeling. As a first step, stationarity checks were performed using the Augmented Dickey-Fuller (ADF) test to ensure that the variables meet the requirements for time series analysis. Initial results indicated that all three series were non-stationary in their level form, meaning they exhibited trends or other non-constant statistical properties over time. Applying first differencing transformed GDP per capita growth and the unemployment rate into stationary series, while the new company formation series remained non-stationary. A second differencing was therefore applied to the new company data, which successfully achieved stationarity. This transformation process ensures that all variables are now suitable for subsequent vector autoregression (VAR) and impulse response function (IRF) analyses, minimizing the risk of spurious regression results and enabling reliable dynamic relationship estimation.

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2025 Volume 13 Number 2 (December)
https://doi.org/10.9770/n5249698324

The Granger causality results from Table 6 reveal bidirectional relationships between GDP per capita and new company formation, although the statistical significance varies with lag length. Specifically, the chi-square test indicates that new company formation Granger-causes GDP per capita at a lag of three years, while GDP per capita Granger-causes new company formation at lags two and three years. This suggests a dynamic interplay where entrepreneurial activity and economic growth reinforce each other, although with some temporal delay. For labor market dynamics, the results show that new company formation Granger-causes unemployment at a lag of two years, and unemployment also Granger-causes new company formation at the same lag. This bidirectional relationship might indicate that job market conditions influence entrepreneurial behavior, while business creation subsequently affects employment opportunities. However, significance is not consistent across all lags, implying that these effects are context- and period-specific. Overall, the findings support the presence of time-lagged feedback loops between economic growth, business formation, and unemployment in the Liberec region, emphasizing the importance of considering temporal dynamics when designing regional economic policies.

Table 6. Granger Causality Test Results (GDP per capita, New Companies, and Unemployment - Liberec Region)

Direction of Causality	Lags	F-statistic	p-value	Chi-square	p-value	Significant at 5%?
New Companies → GDP	1	0.5813	0.4585	0.7059	0.4008	No
	2	0.8684	0.4465	2.5264	0.2827	No
	3	1.9131	0.2060	10.7611	0.0131	Yes (Chi²)
GDP → New Companies	1	1.6575	0.2188	2.0126	0.1560	No
	2	2.7237	0.1094	7.9234	0.0190	Yes (Chi²)
	3	1.4642	0.2956	8.2361	0.0414	Yes (Chi²)
New Companies → Unemployment	1	0.4753	0.5018	0.5771	0.4474	No
	2	2.4574	0.1311	7.1488	0.0280	Yes (Chi²)
	3	0.2788	0.8393	1.5680	0.6667	No
Unemployment → New Companies	1	1.7585	0.2060	2.1353	0.1439	No
	2	2.6433	0.1155	7.6895	0.0214	Yes (Chi²)
	3	1.0075	0.4382	5.6669	0.1290	No

Source: Own Research

Vector Autoregression (VAR) and Impulse Response Analysis: The VAR(3) model from Table 7 shows that GDP growth in the Liberec region is heavily impacted by its own historical values, with all three lag factors (L1-L3) having substantial and negative coefficients. This shows a pattern of mean reversion, in which strong GDP growth in one era is followed by reduced growth in succeeding periods. Furthermore, the model shows that unemployment fluctuations with a three-year lag have a positive and statistically significant effect on GDP growth. This unexpected conclusion might be due to delayed labor market adjustments or cyclical effects, in which earlier unemployment reductions result in stronger productivity and production increases after a lag. Furthermore, new business creation (at lag 3) has a minor but substantial negative influence on GDP growth, which might reflect short-term disruption costs or that newly founded enterprises need time to contribute favorably to the economy. No variables were statistically significant at conventional levels in the unemployment and new firm formation equations, indicating that these factors have weaker direct short-term predictive associations within the specified lag structure. The residual correlation matrix shows a high negative correlation (-0.70) between GDP growth and changes in unemployment, as predicted by economic theory, and a moderate positive correlation (0.50) between GDP growth and changes in new firm creation (Table 8).

Table 7. Model order selection criteria (minimum values highlighted):

Lag	AIC	BIC	FPE	HQIC
0	14.32	14.46	1.651e+06	14.31
1	14.63	15.20	2.351e+06	14.62
2	15.03	16.02	4.256e+06	15.02
3	12.42	13.83	5.646e+05	12.40

Note: The selected optimal lag length is **3**, based on AIC, BIC, FPE, and HQIC.
Source: Own Research

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
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Table 8. VAR(3) Model Results - GDP Growth, Unemployment, and New Company Formation

Dependent Variable	Variable	Coefficient	Std. Error	t-Stat	p-Value	Sig.
GDP_diff	const	1.7996	0.6668	2.699	0.007	Yes
	L1.GDP_diff	-0.7560	0.2117	-3.572	0.000	Yes
	L1.Unemp_diff	0.0315	0.6644	0.047	0.962	No
	L1.NewCo_diff2	0.0037	0.0029	1.272	0.203	No
	L2.GDP_diff	-1.1079	0.2087	-5.308	0.000	Yes
	L2.Unemp_diff	-0.5871	0.5897	-0.996	0.319	No
	L2.NewCo_diff2	0.0002	0.0027	0.076	0.939	No
	L3.GDP_diff	-1.0006	0.2490	-4.019	0.000	Yes
	L3.Unemp_diff	1.6391	0.6161	2.661	0.008	Yes
	L3.NewCo_diff2	-0.0058	0.0021	-2.792	0.005	Yes
Unemp_diff	const	-0.4486	0.3265	-1.374	0.169	No
	L1.GDP_diff	0.0209	0.1036	0.202	0.840	No
	L1.Unemp_diff	0.2800	0.3253	0.861	0.389	No
	L1.NewCo_diff2	-0.0004	0.0014	-0.299	0.765	No
	L2.GDP_diff	0.0424	0.1022	0.415	0.678	No
	L2.Unemp_diff	-0.1116	0.2887	-0.386	0.699	No
	L2.NewCo_diff2	0.0001	0.0013	0.058	0.954	No
	L3.GDP_diff	-0.0012	0.1219	-0.010	0.992	No
	L3.Unemp_diff	-0.0793	0.3017	-0.263	0.793	No
	L3.NewCo_diff2	0.0006	0.0010	0.546	0.585	No
NewCo_diff2	const	-67.4645	97.8060	-0.690	0.490	No
	L1.GDP_diff	-11.0341	31.0449	-0.355	0.722	No
	L1.Unemp_diff	-36.0637	97.4448	-0.370	0.711	No
	L1.NewCo_diff2	-0.1341	0.4264	-0.314	0.753	No
	L2.GDP_diff	37.9190	30.6113	1.239	0.215	No
	L2.Unemp_diff	-39.8623	86.4864	-0.461	0.645	No
	L2.NewCo_diff2	-0.0479	0.3910	-0.122	0.903	No
	L3.GDP_diff	-16.0792	36.5149	-0.440	0.660	No
	L3.Unemp_diff	-78.9104	90.3595	-0.873	0.383	No
	L3.NewCo_diff2	0.0279	0.3041	0.092	0.927	No

Note: Significance at the 5% level is marked as Yes.
Source: Own Research

Table 9. Correlation matrix of residuals:

	GDP_diff	Unemp_diff	NewCo_diff2
GDP_diff	1.000	-0.702	0.503
Unemp_diff	-0.702	1.000	0.111
NewCo_diff2	0.503	0.111	1.000

Source: Own Research

The impulse response (Figures 4 and 5) study indicates that GDP shocks produce transient impacts, with early growth momentum dissipating within two years. Shocks to unemployment have diverse effects, whereas shocks to the establishment of new businesses have little to no effect on GDP or unemployment. In the same way, shocks to GDP impact company development, whereas shocks to unemployment only create short-term changes. In general, the connections between GDP, unemployment, and entrepreneurship are weak. They have only a little short-term impact and greater signs of delayed or outside influences.

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2025 Volume 13 Number 2 (December)
https://doi.org/10.9770/n5249698324

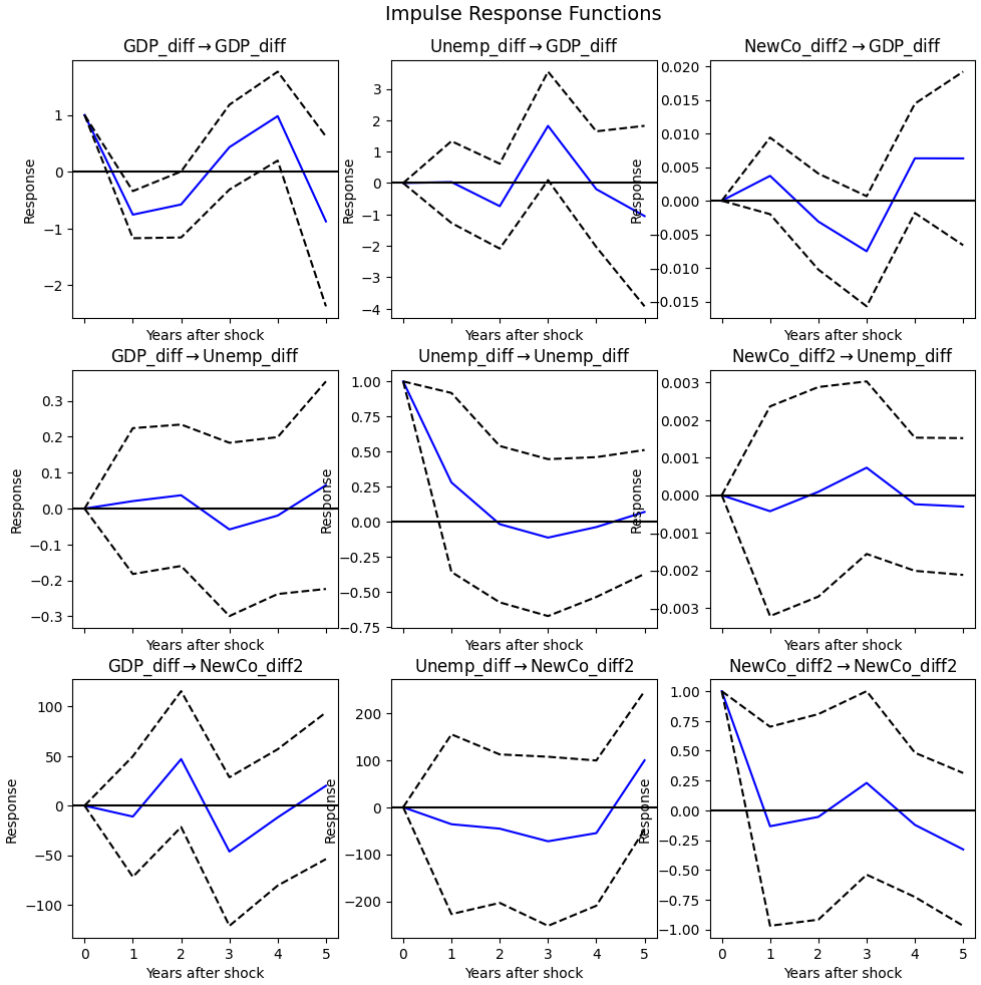


Figure 4. Impulse Response Functions for GDP Growth, Unemployment, and New Company Formation
Source: Own Research

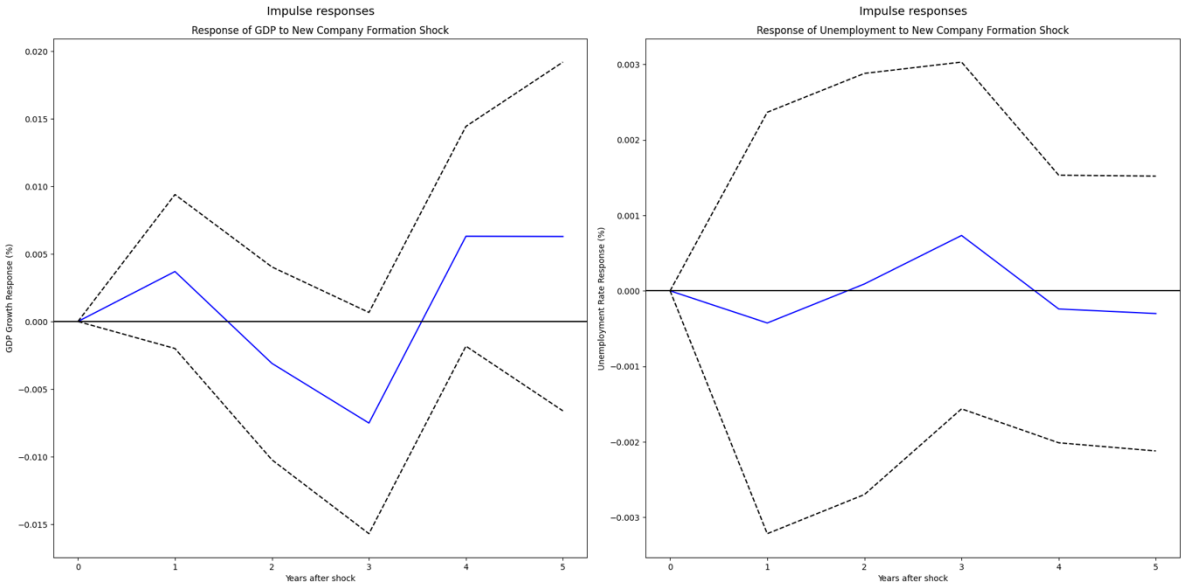


Figure 5. Responses of GDP Growth and Unemployment to a New Company Formation Shock
Source: Own Research

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5. Discussion of Results

Relationship between GDP per capita, new companies, unemployment, average income, and investment rate: The RQ1 study indicates that although GDP per capita is affected by several factors, only unemployment and average income have significant and persistent influences. Unemployment has a negative effect, which is in line with Okun's Law, whereas increased earnings have a favorable effect on growth. New businesses and investments didn't have any big short-term benefits, perhaps because of problems with firm survival, disparities in efficiency, and multicollinearity. In simplified models, unemployment continued to be a big negative effect, while investment seemed to be a positive one. However, entrepreneurship still didn't seem to matter. Overall, the functioning of the labor market and growing earnings have the most effect on regional growth in Liberec. In the near term, entrepreneurship and investment don't matter as much. This means that their effects are more delayed and depend on quality rather than quantity. So, policy should focus on lowering unemployment and encouraging long-term income growth, while also encouraging productive, creative companies over just more of them.

Dynamic and Causal Relationships Between GDP per Capita, New Companies, and Unemployment: Stationarity tests showed that GDP and unemployment were stable after the first differencing, while new enterprises needed the second differencing. Granger causation showed a delayed two-way relationship between GDP per capita and the creation of new businesses. Economic development encourages entrepreneurship after 2–3 years, while new businesses need time to add to GDP. The connection between new businesses and unemployment was not strong and didn't always hold up. There was some indication of mutual effect at two-year delays. The VAR(3) model showed that GDP growth is mostly caused by its own historical values. Unemployment (positive at lag 3) and new firm creation (negative at lag 3, which means short-term adjustment costs) both have delayed impacts on GDP growth. No notable predictors were identified in the unemployment or new company equations, indicating the influence of external structural issues. The findings indicate that entrepreneurship fosters growth only after a certain period, whereas the consequences of unemployment are indirect and less substantial. This shows that regional growth can only happen if there is long-term, continuous policy support for entrepreneurship.

6. Conclusion

This study examined the relationship among GDP per capita, new company formation, and unemployment in the Liberec Region (2002–2024), utilizing stationarity diagnostics, Granger causality tests, and a Vector Autoregression (VAR) framework. The results show that there is a delayed, two-way link between entrepreneurship and economic growth. For example, GDP growth leads to the creation of new businesses, while entrepreneurship leads to an increase in the long run. Conversely, the relationship between entrepreneurship and unemployment was shown to be weaker and less stable, indicating that the impacts on job creation are contingent upon larger structural and regulatory frameworks. The VAR findings showed that GDP dynamics are affected by both their own past values and the lagged impacts of unemployment and entrepreneurship. This shows how regional economic linkages might take time to show themselves. The consequences for policy show that entrepreneurship needs long-term assistance that lasts. Short-term actions alone are unlikely to yield rapid enhancements in the labor market; nevertheless, promoting high-quality, innovative enterprises and fortifying institutional frameworks can yield long-term growth benefits. The study has certain problems, such as a short dataset, a restricted range of variables, and the necessity for differencing, which might hide long-term correlations. Future studies ought to augment the dataset, including supplementary macroeconomic and institutional variables, and utilize sophisticated methodologies such as VECM or non-linear models to comprehensively capture both short-term and long-term dynamics.

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TOWARDS SUSTAINABLE DIGITAL TRANSFORMATION IN INDUSTRIAL ENTERPRISES WITH A FOCUS ON THE CZECH REPUBLIC*

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Abstract. This article presents a comprehensive review of current trends, barriers, and opportunities in sustainable digital transformation within the manufacturing sector, with an emphasis on Central and Eastern Europe. Drawing on a systematic analysis of 85 peer-reviewed studies published between 2020 and 2025, the review identifies the main factors influencing the successful adoption of information systems (IS) and artificial intelligence (AI) in industrial enterprises. The results highlight that the most significant long-term performance and sustainability gains are achieved when technological innovation is combined with the development of digital skills, open organizational culture, and strategic approaches to environmental management. The review further outlines persistent barriers – including human, organizational, and technological challenges – as well as the lack of locally tailored frameworks and empirical evidence for Central and Eastern Europe. By synthesizing these findings, the article provides practical guidance and conceptual clarity for both practitioners and researchers aiming to support effective and sustainable digital transformation in manufacturing.

Keywords: digital transformation; Artificial Intelligence (AI); sustainability; information systems; manufacturing; organizational culture; Central and Eastern Europe; Czech manufacturing sector

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JEL Classifications: M21, L25, M15

1. Introduction

The global manufacturing industry is experiencing a fundamental digital transformation driven by technologies associated with Industry 4.0 – such as artificial intelligence (AI), the Internet of Things (IoT), and big data analytics – which are rapidly reshaping production processes and business models (Chilunjika, 2024; Li et al., 2025). These innovations deliver higher operational efficiency, enable real-time, data-driven decision-making, and support the development of new business models oriented towards sustainable growth (Li et al., 2025).

Simultaneously, the imperative of sustainability is gaining prominence. In response to climate change and pressure to reduce emissions, enterprises are increasingly required to pursue sustainable operations alongside digital transformation (Ezzat, 2023). The World Economic Forum underscores that companies must align digital and sustainable transformation, as only their integration can ensure compatibility with low-carbon economic

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goals (Ezzat, 2023). Advanced digital technologies can significantly reduce the environmental footprint of manufacturing – through sustainable product design, circular approaches, and improved efficiency of resources – which strengthens long-term resilience and competitiveness (Ezzat, 2023).

For the Czech Republic, with its highly industrialized economy and strong integration into international value chains, these global trends are especially relevant. The manufacturing sector forms the backbone of the national economy, with the automotive industry alone accounting for roughly a quarter of total exports (Keay, 2024). However, the historical advantage of low-cost labor is now diminishing. The Czech economy faces the so-called middle-income trap, where wage and price growth outpaces productivity increases, undermining long-term competitiveness (Keay, 2024). Chronic labor shortages – particularly of skilled workers – further exacerbate these challenges, as the country's unemployment rate remains among the lowest in the EU, intensifying wage pressures and increasing unit labor costs (IMF, 2024).

Alongside these external pressures, domestic barriers persist. Excessive administrative burden and slow permitting processes hinder business development, and international organizations recommend simplifying regulation and further digitalizing public administration (IMF, 2024). Another persistent challenge is the relatively low level of digitalization among many firms, especially small and medium-sized enterprises (SMEs): only about half of Czech SMEs achieve basic digital intensity, compared to an EU average of approximately 58% (European Commission, 2024). This digital divide leads to lower productivity and innovation in lagging firms, ultimately constraining sectoral growth.

From a sustainability perspective, the Czech manufacturing sector is also characterized by high energy intensity, with much of its energy mix still reliant on fossil sources (IMF, 2024). The path to climate neutrality by 2050 – aligned with EU strategy – will require substantial investments and innovations, especially in energy management, smart grids, and AI-driven optimization.

Given these circumstances, it is clear that Czech manufacturing enterprises face an urgent need for comprehensive transformation that links digital innovation with sustainability principles. Sustainable digital transformation represents a strategic response, involving the deployment of advanced information systems, automation, and AI, as well as measures to reduce the environmental footprint of production. Only through such dual transformation can Czech industry enhance performance, resilience, and meet rising regulatory and customer demands for sustainable operations.

This article analyzes global trends in digital transformation in manufacturing from a sustainability perspective and examines their consequences for Czech industrial companies in the context of the ongoing Fourth Industrial Revolution.

2. Literature Review

2.1 The Impact of Information Systems and AI on Firm Performance

The adoption of advanced information systems (IS) and artificial intelligence (AI) technologies has been recognized as a primary driver of performance growth in manufacturing enterprises in recent years. Research consistently demonstrates positive effects of these technologies on labor productivity, process efficiency, and innovation capacity (Blichfeldt & Faullant, 2021; Zhang et al., 2023; Gastaldi et al., 2022). Modern IS support improved production planning, monitoring, and real-time control, while AI enables predictive maintenance, automated decision-making, and advanced data analytics (Mohamed et al., 2022; Tortorella et al., 2022; Bai et al., 2022).

The introduction of IS and AI also facilitates faster innovation and greater flexibility. Enterprises can better personalize products, respond to shifts in demand, and shorten innovation cycles (Chirumalla, 2021; Enrique et al., 2022). However, the benefits differ significantly between larger and smaller firms. Larger companies are more likely to possess advanced data infrastructures, strategic leadership, and better access to skilled employees, allowing them to realize a faster return on investment (Kubickova et al., 2021; Vlachos et al., 2023).

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2025 Volume 13 Number 1 (September)
http://doi.org/10.9770/j2336895982

Recent studies have expanded the application of information systems and decision-support models beyond manufacturing, demonstrating their role in tourism, healthcare, and media ecosystems, investment areas (Peternel & Bukvič, 2024). Gavurova et al. (2025) highlight the socio-economic impact of digital transformation in tourism, introducing a hybrid decision-support model that enhances regional competitiveness. Complementary research by Gavurova and Polishchuk (2025) employs fuzzy set theory to design travel planning systems for people with disabilities, showing how digital tools can foster inclusivity. In parallel, Moravec et al. (2025) investigate algorithmic personalization, emphasizing both its potential for efficiency and the risks associated with digital literacy gaps. Healthcare applications have also been explored: Smolanka et al. (2024) evaluate the integration of information technologies in hospitals, while Gavurova, Smolanka, and Polishchuk (2024) propose an intellectual model for managing patient trust in medical staff. Moreover, studies in media and regional development contexts demonstrate how advanced IS can inform policy and investment decisions - such as assessing automated news content for media literacy (Gavurova et al., 2024) and evaluating large-scale tourism infrastructure projects (Skare, Gavurova & Polishchuk, 2023). Collectively, these findings illustrate the versatility of IS and AI-driven decision models, extending their benefits from firm-level efficiency to societal, healthcare, and regional outcomes.

2.2 Barriers to Implementation: Human, Organizational, and Technological Challenges

The successful implementation of IS and AI is not automatic and faces multiple barriers, which can be categorized as human, organizational, and technological. *Human barriers* include resistance to change, low digital literacy, insufficient motivation for further training, and limited awareness of the benefits of digitalization (Chauhan et al., 2021; Gastaldi et al., 2022). Frequently, there is also a lack of leadership support, vision, or willingness to invest in employee development (Kubickova et al., 2021; Bhatia & Kumar, 2022; Stoyanova & Angelova, 2024). *Organizational barriers* involve rigid structures, isolation of IT from operations, and the absence of coordination between management levels (Amaral & Peças, 2021; Enrique et al., 2022; Erboz et al., 2022). *Technological barriers* stem from inadequate infrastructure, poor data quality, lack of standards, and complications integrating new and legacy systems (Dhirani et al., 2021; Alabadi et al., 2022). In the Czech context, a conservative management approach and low trust in data sharing across supply chains also play a significant role (Chauhan et al., 2021; Amaral & Peças, 2021; Pfaff, 2023).

2.3 The Role of Leadership, Culture, and Digital Skills

Previous authors agree that technological maturity alone does not guarantee the success of digital transformation. Leadership is a key factor—the ability to create a digital vision, foster trust, and guide change (Adebanjo et al., 2023; Gastaldi et al., 2022). Successful adopters invest in the development of digital skills at all organizational levels, from operators to managers (Bhatia & Kumar, 2022; Lai et al., 2023), and build a culture of openness, collaboration, and data-driven learning (Chirumalla, 2021; Virmani et al., 2023). The ability to connect technological advancement with human factors is one of the main determinants of long-term success (Enrique et al., 2022; Ali & Johl, 2022).

2.4 Digitalization and Sustainability

Modern IS and AI are increasingly important for environmental sustainability and green innovation. Digital tools enable real-time monitoring and optimization of energy, material, and emissions (Favi et al., 2022; Lai et al., 2023; Ye et al., 2023). They are especially relevant in green supply chain management, circular economy practices, predictive maintenance, and sustainable product design (Khan et al., 2021; Song et al., 2022; Torrent-Sellens et al., 2023; Bag et al., 2023). Empirical studies confirm that firms investing in digital green solutions achieve both environmental and economic benefits – such as lower energy consumption, higher recycling rates, and improved resource efficiency (Karmaker et al., 2023; Asif et al., 2024). Such investments also enhance reputation and help enterprises meet stricter regulatory and customer demands.

2.5 Research Gaps

Despite rapid research development in IS/AI in manufacturing, several important gaps persist, especially in the Central and Eastern European context:

- Lack of case studies reflecting the specificities of post-transformation economies (Kubickova et al., 2021; Amaral & Peças, 2021).

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2025 Volume 13 Number 1 (September)
http://doi.org/10.9770/j2336895982

- Absence of localized implementation frameworks adapted to the needs of Czech industry (Adebanjo et al., 2023; Yu et al., 2021).
- Limited quantitative evidence of real impacts—qualitative or declarative approaches still dominate (Ghobakhloo et al., 2024; Zhang et al., 2023).
- Fragmented treatment of digitalization and sustainability—most studies address economic, technological, and environmental aspects separately, without a systemic perspective (Kedir & Hall, 2021; Mohamed et al., 2022; Bag et al., 2023).

These findings point to several important avenues for future progress, including the development of localized implementation frameworks, greater use of quantitative research methods, and a stronger focus on the practical needs and challenges of Central European manufacturing enterprises.

3. Methodology

This study is based on a systematic literature review designed to analyze the relationship between digital transformation – particularly the implementation of information systems (IS) and artificial intelligence (AI) – and firm performance in the manufacturing sector. The review aimed to map the current state of scientific knowledge, identify key trends, research approaches, documented benefits and barriers to implementation.

3.1 Search Strategy

The literature review was conducted using the Web of Science (WoS) database, employing the Advanced Search Query Builder to cover the core topics of advanced AI, firm performance, the manufacturing sector, and digital technology adoption.

3.2 Selection and Filtering Criteria

An initial pool of 220 scientific articles was collected and filtered according to the following criteria:

- Publication period: 2020–2025
- Document type: Peer-reviewed articles and review articles
- Research fields: Engineering (industrial, manufacturing, multidisciplinary), economics and management, information technology, and related technical disciplines
- Language: English only
- Indexing: SCI-EXPANDED, SSCI, ESCI

3.3 Relevance Assessment and Final Sample

Each article was evaluated using a four-level relevance scale:

- 3: High relevance (direct connection to the research aim, e.g., empirical studies on the impact of AI/IS on manufacturing firm performance)
- 2: Medium relevance (partial thematic overlap, e.g., studies on technology adoption or broader digitalization impacts)
- 1: Low relevance (marginal relation to the topic)
- 0: Irrelevant (outside the research scope)

Additionally, a quantitative metric called "article value" was calculated as:
Article value = Number of citations + (Relevance × 10)
Only articles with a value ≥ 30 and at least medium relevance were included in the final sample. This process yielded 85 full-text articles that met both qualitative and quantitative requirements.

3.4 Statistical and Thematic Distribution

The majority of selected publications were from the last four years, reflecting the dynamism of research in this field:

- 2021: 24 articles
- 2022: 28 articles
- 2023: 23 articles
- 2024: 13 articles

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2025 Volume 13 Number 1 (September)
http://doi.org/10.9770/j2336895982

Thematically, the articles covered digital transformation in manufacturing, the impact of IS/AI on productivity, change management and human factors, implementation barriers, green innovations, circular economy, smart manufacturing, and the integration of Lean and Industry 4.0. Geographically, the sample included studies from China, India, the United Kingdom, the United States, Italy, Germany, France, Spain, and Australia, reflecting broad international interest and enabling comparative interpretation across diverse economic and cultural contexts.

4. Findings and Discussion

Recent empirical research in Central and Eastern Europe further supports the crucial role of digital transformation and Industry 4.0 in improving firm performance and advancing sustainability outcomes. For instance, Krulický et al. (2024) demonstrate that the adoption of Industry 4.0 technologies among Czech manufacturing companies leads to significant increases in process efficiency and resource optimization, particularly through the reduction of waste and energy consumption. These results align with findings from Grenčíková et al. (2021), who emphasize that digitalization and automation helped Slovak enterprises increase their resilience and adaptability during the Covid-19 pandemic, thereby supporting business continuity in turbulent environments.

However, several studies highlight that the success of digital transformation is not determined by technology adoption alone. Tang and Zhou (2025) argue that unlocking the growth potential of underused resources within companies depends both on digital transformation and on robust decision-making capabilities at the managerial level. Importantly, a growing number of authors directly link digital transformation to sustainability performance. Burinskienė et al. (2025) and Peclinovský et al. (2024) provide empirical evidence that investments in digital technologies and Industry 4.0 lead to enhanced environmental outcomes, such as improved resource efficiency and reduced emissions in supply chains. These findings confirm that the integration of digitalization and sustainability is a key pathway for industrial enterprises seeking to achieve long-term competitiveness and resilience in a rapidly changing environment.

Nonetheless, as Talíř and Chytilová (2024) observe, digitalization alone may not guarantee immediate financial improvements, especially in crisis situations. This underscores the need for holistic strategies that combine technology, human capital development, and organizational change. The lessons drawn from these recent studies reinforce the relevance and urgency of developing context-specific and localized frameworks to maximize the benefits of digital transformation in Central and Eastern Europe.

4.1 Key Drivers of Successful Digital Transformation

Multiple authors confirm that the successful and sustainable digital transformation of manufacturing enterprises is determined by four mutually reinforcing domains: technological infrastructure, human competencies, organizational culture, and strategic sustainability orientation (Blichfeldt & Faullant, 2021; Bhatia & Kumar, 2022; Virmani et al., 2023; Bag et al., 2023). These areas serve as the axes of transformational readiness and form the basis for a practical framework for both businesses and policymakers.

Technological Enablers

Key technological factors include the availability and integration of IS/AI systems, data quality, interoperability of systems, and the use of cloud platforms, IoT, and predictive analytics (Blichfeldt & Faullant, 2021; Matin et al., 2023; Duan & Xu, 2024). Firms with robust technological foundations are better positioned to achieve productivity gains and rapid innovation.

Competencies and Human Capital

Developing digital skills at all organizational levels – facilitated through internal training, external education, and partnerships with academic institutions – is crucial. The ability to collaborate across IT and operations, continuous learning, and upskilling are repeatedly highlighted as essential for transformation success (Chirumalla, 2021; Bhatia & Kumar, 2022; Lai et al., 2023).

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2025 Volume 13 Number 1 (September)
http://doi.org/10.9770/j2336895982

Organizational Culture and Change Management
An open, innovation-oriented culture, participative leadership, transparent communication, and the active involvement of employees in digital initiatives are strong enablers of long-term success (Virmani et al., 2023; Gastaldi et al., 2022; Pfaff, 2023). Change management practices must prioritize employee engagement and trust in technology.

Sustainability as a Strategic Principle
Integrating environmental management, green supply chain practices, and circular economy principles is becoming a standard part of digital transformation strategies (Bag et al., 2023; Torrent-Sellens et al., 2023; Asif et al., 2024). Successful companies systematically include environmental metrics in their KPIs and leverage AI to optimize resource consumption and minimize emissions.

4.2 Barriers and Challenges

Despite the potential benefits, manufacturing enterprises face a range of persistent barriers:

- Human barriers: Resistance to change, low digital literacy, and limited motivation for further education impede progress (Chauhan et al., 2021; Gastaldi et al., 2022).
- Organizational barriers: Rigid hierarchies, poor integration between IT and production, and lack of cross-functional coordination are common obstacles (Amaral & Peças, 2021; Enrique et al., 2022; Erboz et al., 2022).
- Technological barriers: Legacy infrastructure, inadequate data quality, lack of interoperability, and integration challenges complicate the deployment of new systems (Dhirani et al., 2021; Alabadi et al., 2022).
- In the Czech context, conservative leadership and a lack of trust in data sharing across value chains present additional obstacles (Chauhan et al., 2021; Amaral & Peças, 2021; Pfaff, 2023).

4.3 The Interplay Between Digitalization and Sustainability

Modern IS and AI technologies are key enablers not only for operational performance but also for environmental sustainability. Digital tools allow for real-time monitoring and optimization of energy use, material flows, and emissions, contributing to both ecological and economic benefits (Favi et al., 2022; Lai et al., 2023; Ye et al., 2023). Green supply chain management, circular economy practices, and AI-driven predictive maintenance are examples of how digitalization supports sustainability goals (Khan et al., 2021; Song et al., 2022; Torrent-Sellens et al., 2023; Bag et al., 2023).

4.4 Future Directions

According to recent authors, there are several areas that warrant further exploration, particularly in the context of Central and Eastern European manufacturing:

- Lack of contextualized case studies: There is a shortage of empirical studies reflecting the unique conditions of post-transformation economies (Kubickova et al., 2021; Amaral & Peças, 2021).
- Absence of localized implementation frameworks: Adapted approaches are needed for the specific challenges of Czech industry, including company size, organizational structure, and culture (Yu et al., 2021; Adebanjo et al., 2023).
- Need for more quantitative evidence: Much of the current research relies on qualitative or declarative findings, emphasizing the need for robust quantitative studies (Zhang et al., 2023; Ghobakhloo et al., 2024).
- Systemic integration of digitalization and sustainability: Future research should address these areas in a holistic manner, rather than as separate domains (Kedir & Hall, 2021; Mohamed et al., 2022; Bag et al., 2023).

4.5 Four-dimensional Assessment Framework for Sustainable Digital Transformation

Based on the synthesis of recent studies, a **four-dimensional assessment framework** is proposed to guide manufacturing enterprises and policymakers in planning and implementing sustainable digital transformation initiatives. The framework encompasses four key domains – **technology, competencies, culture, and sustainability –** which jointly determine transformational readiness and long-term impact.

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2025 Volume 13 Number 1 (September)
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Table 1. Four-dimensional assessment framework

Domain	Key Questions for Assessment
Technology	Are advanced IS/AI systems implemented? Are they interoperable? Is there access to relevant data and analytics?
Competencies	Does the organization possess the necessary digital skills for new technologies? Are there ongoing investments in employee development?
Culture	Does the organizational culture support innovation and collaboration? Is leadership actively driving and communicating the transformation?
Sustainability	Are environmental measures in place? Are energy consumption, CO_2 emissions, and waste systematically monitored and managed? Is green tech utilized?

This framework can be utilized for **self-assessment** within organizations (e.g., via maturity matrices) or as a **strategic management tool** for driving change. Its application allows enterprises to evaluate not only technical readiness but also the softer organizational factors that are critical for the long-term sustainability of digital transformation.

By integrating these four domains, companies are better equipped to turn isolated digital initiatives into comprehensive, systemic change – thereby enhancing both economic performance and environmental resilience.

5. Conclusions

This article has explored the trends, barriers, and opportunities of sustainable digital transformation in the manufacturing sector, with a particular focus on the Czech context. The systematic review of 85 peer-reviewed articles confirms that advanced information systems and artificial intelligence have significant potential to improve organizational performance through automation, predictive analytics, process optimization, and more efficient use of resources. However, the success and sustainability of digital transformation depend on the synergistic interaction of four critical domains: technology, competencies, organizational culture, and strategic sustainability orientation.

Integrating these domains allows enterprises to transform fragmented digital initiatives into deeper structural change, leading to long-term gains in both performance and environmental impact. The proposed four-dimensional assessment framework offers a practical tool for organizations and policymakers to assess digital maturity and prioritize actions for sustainable transformation.

For Czech manufacturing, this agenda is especially urgent due to labor shortages, rising costs, decarbonization pressures, and evolving customer demands. At the same time, there remains a lack of localized frameworks, empirical evidence, and validated best practices tailored to Central and Eastern European industry. Addressing these gaps represents a significant opportunity for both researchers and practitioners. This article is based solely on a systematic literature review and conceptual synthesis. It does not provide primary empirical data; the proposed framework therefore requires empirical validation – such as through case studies, surveys, or action research within industrial enterprises.
Several promising avenues for further research emerge from this review:

- Quantitative assessment of the impact of IS/AI adoption on sustainability metrics (e.g., energy consumption, carbon footprint, recyclability).
- Development and testing of adaptive and scalable frameworks for small and medium-sized enterprises.
- Exploration of the roles of leadership and organizational culture in digital transformation across different types of companies.
- Integration of ethical and security aspects (e.g., AI governance, cybersecurity) into frameworks for sustainable digitalization.

Overall, digital transformation and sustainability are not separate challenges, but interconnected and mutually reinforcing. Only those companies that can align technological progress with competence development,

innovative culture, and a strategic approach to sustainability will succeed in the dynamic environment of the 21st-century global economy.

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PECULIARITIES OF LOGISTICS AND DIGITAL INTEGRATION BETWEEN KAZAKHSTAN AND THE EU*

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Abstract. This article presents a comprehensive analysis of the development of transport and logistics cooperation between Kazakhstan and the European Union, with a particular focus on the specific role of Latvia as a strategic gateway for Eurasian freight flows. The study examines institutional reforms, digital integration, and innovative approaches to managing transit corridors, which contribute to the diversification of export–import flows and enhance regional competitiveness. Employing an interdisciplinary methodology, the research applies comparative institutional analysis, case studies, and empirical statistical data. Key drivers of digital transformation include the implementation of electronic platforms, customs automation, and the development of multimodal transport systems. The findings demonstrate that Latvia's active participation in EU infrastructure and digital projects significantly strengthens Kazakhstan's position in the European market, ensuring resilience and efficiency of logistics chains amid global geopolitical and economic challenges. The article offers practical recommendations for improving institutional compatibility, developing unified digital standards, and scaling transport and logistics corridors within the Eurasian space.

Keywords: digital integration; European Union; institutional cooperation; Kazakhstan; Latvia; logistics; transport corridors; transit

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Additional disciplines: logistics, information technology, political science

1. Introduction

The economic partnership between the European Union and Kazakhstan is reaching a new level, encompassing not only traditional trade in raw materials but also joint projects in industry, innovation, and the green economy (Zharmakhanova et al., 2024; Mukasheva et al., 2024; Hussain et al., 2024). In 2023, EU countries accounted for approximately 27.9% of Kazakhstan's foreign trade and 37% of its exports, while the total accumulated

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European investments reached €54.8 billion, increasing by 5.5% compared to the previous year (Tonkonog, 2023; European Commission, 2023).

Key investors in the Kazakhstani economy in recent years include companies such as Eni (Italy), TotalEnergies (France), and Royal Dutch Shell (Netherlands/UK) in the oil and gas sector, as well as Carlsberg Group (Denmark) and Alstom (France) in engineering and transport. In 2022, the French company Alstom invested in expanding local locomotive production in Nur-Sultan, while the German firm Svevind launched Central Asia's largest renewable energy project, worth up to $50 billion, focused on wind and solar power. These investments strengthen Kazakhstan's economic diversification and its focus on green energy (Akhmetkali, 2023; Poberezhskaya & Bychkova, 2022; European Commission, 2023).

Diversifying the commodity structure has become a strategic priority. Beyond hydrocarbons (oil, gas) and uranium, Kazakhstan's exports to the EU increasingly include metallurgical products (refined copper, ferroalloys, zinc, aluminum), grains (wheat), chemical and petrochemical goods, as well as growing volumes of machinery and agro-industrial products (Observatory of Economic Complexity (OEC), 2024; Nakhle, 2023; European Commission, 2023). From the EU side, the most demanded imports into Kazakhstan are industrial equipment, automobiles, electrical goods, pharmaceuticals, and services in digital infrastructure and logistics (European Commission, 2023; Akhmetkali, 2023; Otarbayeva, 2024).

In response to the challenges posed by Kazakhstan's raw material dependence, the country is implementing its National Strategy for Industrial-Innovative Development, alongside special export programs aimed at stimulating the production and export of non-raw goods. Particular emphasis is placed on the development of green technologies, digitalization of industrial clusters, and attracting investment into the processing sector (European Commission, 2022a; Poberezhskaya & Bychkova, 2022).

Amid the transformation of global supply chains driven by geopolitical turbulence (Smorodinskaya et al., 2021), Central Asia – and Kazakhstan in particular – is emerging as a reliable transit and production partner for the EU. This status is supported by initiatives such as Global Gateway and Team Europe's joint projects fostering transport, digital, and energy infrastructure development (Karjalainen, 2022; Figueroa-García & Gélvez-Rubio, 2022; Yerimpasheva & Brauweiler, 2025; European External Action Service (EEAS), 2024; Kazakhstan MFA, 2023). In January 2024, the EU confirmed its readiness to invest €10 billion into the development of the Trans-Caspian International Transport Route (TITR) and the modernization of transport hubs in the region, where Latvia is becoming a key logistics and digital "gateway" to Europe (European Commission, 2024; OECD, 2023). It is important to emphasize that Latvia, as an integral part of the European Union, conducts its foreign economic and logistics policies strictly within the framework of broader EU strategies and regulations (Andersone, 2024). Its special role in partnership with Kazakhstan is not a result of independent geoeconomic choices, but rather a combination of factors: its advantageous geographical position, developed port and railway infrastructure, high level of digitalization, and integration into EU strategic projects on the eastern axis (Karjalainen, 2022). For Kazakhstan, utilizing Latvian transport and digital platforms is a pragmatic decision driven by the need to diversify channels accessing the European market and minimize external logistics and political risks (Muratova et al., 2023).

The objective of this article is to analyze the evolution of economic cooperation between Kazakhstan and the European Union through the lens of Latvia's dual role: as an institutional and infrastructural intermediary integrated into the EU system, and as a regional "partner" in digital, logistics, and innovation spheres. Particular attention is given to the institutional constraints on Latvia's autonomy and the benefits this role offers Kazakhstan amid a changing geoeconomic environment.

2. Literature review

The economic partnership between Kazakhstan and the European Union has been extensively examined in recent studies, emphasizing both trade dynamics and long-term investment strategies. Analysts highlight that the EU remains one of Kazakhstan's most significant economic partners, not only in the export of hydrocarbons but also in the diversification of industries and green transition (Tonkonog, 2023; Akhmetkali, 2023; Nakhle,

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2023; Observatory of Economic Complexity (OEC), 2024). These studies show that European investments increasingly target high-tech sectors, renewable energy, and industrial modernization, reflecting Kazakhstan's strategic orientation toward sustainable development (Otarbayeva, 2024).

EU strategies in Central Asia form another key strand of the literature. Scholars note that the EU seeks to balance its normative agenda with pragmatic interests in energy and connectivity, as outlined in recent policy papers and academic analyses (Karjalainen, 2022; Tvaronaviciene, 2024; European Commission, 2022a; European Commission, 2023; Andersone, 2024; European Commission, 2024; OECD, 2023). The Global Gateway initiative and Team Europe projects are frequently mentioned as central instruments for strengthening connectivity, digitalization, and energy cooperation in the region.

The role of global value chains and external risks has also been emphasized in theoretical contributions. Studies of de-globalization trends and disruptions in supply chains demonstrate how geopolitical turbulence reshapes Kazakhstan–EU relations, forcing both sides to adapt to uncertainty (Antràs, 2020; Smorodinskaya et al., 2021). This perspective frames Kazakhstan not only as a resource supplier but also as a potential production and logistics partner within reconfigured global chains.

Latvia's position as a logistics and digital hub for Kazakhstan–EU cooperation is underlined in both academic and institutional analyses. The country's developed port and railway infrastructure, combined with advanced digital solutions, make it an attractive partner for transit and technological services (Metera, 2022; Moisé & Sorbello, 2022). These works emphasize Latvia's role as part of the broader EU connectivity strategy, rather than as an independent geopolitical actor.

The literature also highlights the growing significance of green energy, innovation, and sustainability in Kazakhstan–EU cooperation. Recent studies stress the role of large-scale renewable energy projects, such as the German Svevind initiative, as well as the integration of environmental and digital innovations into bilateral relations (Poberezhskaya & Bychkova, 2022; European Commission, 2022a; European Commission, 2023). Additionally, Yerimpasheva & Brauweiler (2025) explore the "Global Gateway" as a tool for sustainable growth in Kazakhstan. These projects are seen as markers of a structural shift toward sustainable economic relations between Kazakhstan and the EU. Furthermore, the connection between energy production and the introduction of ICT and the growth of the agricultural-industrial complex is increasingly recognized (Smagulova et al., 2023).

On a more detailed level, research provides a comprehensive overview of specific challenges and opportunities. Temirgalieva and Junussova (2020) and Minazhova et al. (2023) analyze how the introduction of renewable electricity affects the sustainability of Kazakhstan's national and regional power systems.

An overview of the potentials, deployment, outlook, and existing barriers for renewable energy in Central Asia is provided by Laldjebaev et al. (2021). Vechkinzova et al. (2021) explore the long-term dilemmas facing the electric power industry in Kazakhstan. Zholdayakova et al. (2022) explore the strategic potential and roadmap toward a hydrogen economy in the country. In a more specific analysis, Tleubergenova et al. (2023) conducted a detailed resource assessment for green hydrogen production in Kazakhstan.

Overall, the body of literature provides a comprehensive picture of the evolving Kazakhstan–EU partnership. It demonstrates the interplay between economic diversification, EU strategic frameworks, global value chain transformations, Kazakhstan's multivector policy, Latvia's logistical functions, and the shared focus on innovation and sustainability.

3. Trade and economic relations between Kazakhstan and Latvia: dynamics and trends

Trade and economic interaction between Kazakhstan and Latvia in recent years demonstrates not only quantitative growth but also qualitative improvements, reflecting systemic changes in logistics, export structures, and the institutional mechanisms of bilateral cooperation. The dynamics of trade turnover between the two countries are shaped against the backdrop of broader European trends, the expanding opportunities of

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2025 Volume 13 Number 2 (December)
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the Trans-Caspian International Transport Route (TITR), as well as intensified digital and infrastructure initiatives within EU cooperation and structural transformations in global supply chains (Figueroa-García & Gélvez-Rubio, 2022; Smorodinskaya et al., 2021; Birkeland et al., 2021; European Commission, 2023; Muratova et al., 2023).

It is important to emphasize that, in contemporary academic literature, Latvia is viewed not as an independent geoeconomic actor, but as a functional element of the European Union's infrastructure and regulatory environment (Smorodinskaya et al., 2021). Most theoretical approaches highlight that Latvia's "intermediary" role in Eurasian logistics and digital initiatives is a direct consequence of its integration into the pan-European economic and regulatory frameworks, rather than the result of an independent foreign economic policy (see Boonstra, 2019). This status positions Latvia as a flexible and convenient channel for advancing the interests of third countries – particularly Kazakhstan – into the EU market, without turning it into an autonomous regional player.

3.1. General trends and dynamics of trade turnover

In 2023, the volume of bilateral trade between Kazakhstan and Latvia reached a record €275.6 million, marking a 63% increase compared to 2021 (Observatory of Economic Complexity (OEC), 2024; Omirgazy, 2024). This growth is largely driven by the diversification of Kazakhstan's export flows and the shift of transit routes in favor of the Baltic ports amid geopolitical and logistical changes in Eurasia (Muratova et al., 2023; Middle Corridor, 2022).

Table 1. Trade dynamics between Kazakhstan and Latvia (2021–2023)

Year	Kazakhstan's export to Latvia (€ million)	Kazakhstan's import from Latvia (€ million)	Total trade turnover (€ million)
2021	114.0	50.0	164.0
2022	147.0	59.0	206.0
2023	198.4	77.2	275.6

Sources: the authors' compiled based on the data from Bureau of National Statistics of the ASPR RK, 2024.

Kazakhstan's exports to Latvia increased by nearly 1.75 times, while imports grew by more than 54%. A significant role in this growth was played by new contracts for the supply of metals, petroleum products, and agricultural goods, as well as the expansion of cooperation in logistics and transit services. Additionally, strengthened institutional interaction within frameworks such as TRACECA, TITR, and joint digital platforms helped reduce transportation costs and enhance Latvia's attractiveness as a transit country (Saktaganova et al., 2025; Birkeland et al., 2021).

Compared to other Baltic countries, Latvia has taken a leading position in the growth rate of trade turnover with Kazakhstan over the past three years: an increase of 68% surpasses similar figures for Lithuania (+26%) and Estonia (+15%). This is associated both with the expansion of port infrastructure and with the institutional flexibility of Latvian logistics operators (Muratova et al., 2023; European Commission, 2023).

3.2. Export and import structure: diversification and innovation

A structural analysis of Kazakhstan's exports to Latvia reveals a shift from a dominance of raw materials toward a diversified portfolio that includes metals, agricultural products, and chemical goods (Boute, 2020; Observatory of Economic Complexity (OEC), 2024; Nakhle, 2023; Kazakhstan MFA, 2023).

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
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Table 2. Major categories of Kazakhstan's exports to Latvia (2023)

Product	**Volume (€ million)**	**Share (%)**
Refined Copper	80.5	40.6
Coal Briquettes	32.0	16.1
Mineral Fertilizers	16.3	8.2
Grain	10.4	5.2
Uranium, Petroleum Products	23.6	11.9
Others	35.6	18.0

Sources: the authors' compiled based on the data from Observatory of Economic Complexity (OEC), 2024.

The growth in shipments of agricultural and chemical products reflects Kazakhstan's efforts to diversify its exports and develop the non-raw material sector. The presence of uranium, petroleum products, and machinery in the export structure demonstrates the complexity of modern logistics chains and adaptation to European quality and safety standards (Birkeland et al., 2021; Smagulova et al., 2023).

Kazakhstan's imports from Latvia are characterized by a focus on high-tech goods, industrial equipment, pharmaceuticals, and IT solutions, confirming the growing innovative component of bilateral trade (European Commission, 2023; Metera, 2022; Otarbayeva, 2024).

Table 3. Structure of imports from Latvia to Kazakhstan (2023)

Product/Service	**Volume (€ million)**	**Share (%)**
Industrial Equipment	25.9	33.5
Pharmaceuticals	13.8	17.9
IT/Logistics Solutions	8.0	10.4
Transport Components	9.7	12.6
Chemical Products	6.9	8.9
Others	12.9	16.7

Sources: the authors' compiled based on the data from Trading Economics, 2024

The import structure confirms active development in sectors related to production modernization, digitalization of business processes, and the adoption of new technologies in Kazakhstan. Latvia acts here not only as a transit country but also as a provider of high-value-added technological solutions and services. This trend strengthens Kazakhstan's integration into European production and logistics chains (Moisé & Sorbello, 2022).

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
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3.3. Innovation and institutional effects

A qualitative leap in the development of bilateral relations has been made possible through institutional transformations: the entry into force of the EPCA agreement, expanded involvement in the TRACECA and TITR platforms, the implementation of digital solutions, and port infrastructure modernization programs (Birkeland et al., 2021; European Commission, 2019; Saktaganova et al., 2025). Particularly noteworthy is the integration of electronic customs services and the development of systems such as the Baltic Port Community System (PCS), SmartPort Riga, e-Customs Latvia, along with pilot blockchain initiatives for tracking transit containers. These innovations have reduced the average cargo clearance time from 48 to 28 hours and increased the share of electronic exports to 61% by 2023 (Saktaganova et al., 2025).

4. Research Methodology

This chapter presents the methodological foundations of the study, including the theoretical approaches employed, data sources, and analytical methods. A comprehensive interdisciplinary approach combining both quantitative and qualitative methods has been applied, enabling a thorough examination of transport-logistics cooperation and digital integration between Kazakhstan, Latvia, and the European Union. The chapter further details the selection of data, analysis criteria, and procedures for verifying the results.

4.1. Theoretical and methodological foundations

This study is grounded in an interdisciplinary approach that combines comparative economic, institutional, and political-geographical analyses (Birkeland et al., 2021; Baldwin & Tomiura, 2020; Andersone, 2024). The theoretical framework is primarily based on works addressing the Europeanization of post-Soviet economies, the theory of "small states as intermediaries" within Eurasian value chains (Boonstra, 2019; Gulomova, 2023), as well as studies on the strategic integration of energy, logistics, and investment flows between the EU and Central Asia (Andersone, 2024; Moisé & Sorbello, 2022; Metera, 2022; Muratova et al., 2023; Boute, 2020; Smagulova et al., 2023).

Special emphasis is given to research investigating institutional transformations within the frameworks of EPCA, TRACECA, and new EU initiatives such as "Global Gateway" (European Commission, 2019; Akhmetkali, 2023; Antràs, 2020; Gereffi, 2020; Miroudot & Nordström, 2020; Karjalainen, 2022; Harutyunyan, 2022). The methodological foundation draws on contemporary concepts of comprehensive regionalization, network effect theories, and the notion of "flexible economies," alongside analyses of ripple effects and vulnerabilities in global supply chains (Figueroa-García & Gélvez-Rubio, 2022; Birkeland et al., 2021; Muratova et al., 2023), allowing for the recognition of the multidisciplinary nature of Kazakhstan-Latvia cooperation and the hybrid character of modern logistics platforms.

4.2. Sample and structure of empirical data

To ensure the validity and comparability of the analysis, the following data sources were used:

- International statistical databases (UN COMTRADE, OEC) covering trade dynamics and structure, service flows, as well as product and regional breakdowns for the period 2010–2023 (Observatory of Economic Complexity (OEC), 2024; Omirgazy, 2024; Khitakhunov, 2023);
- Official reports from the European Union, governments, and industry associations (European Commission, 2023; Middle Corridor, 2022);
- Publications by international organizations and research centers (European External Action Service (EEAS), 2022; Moisé & Sorbello, 2022);
- Peer-reviewed academic articles addressing issues of institutional integration, energy, export diversification, and logistics connectivity (Metera, 2022; Muratova et al., 2023; Gulomova, 2023;Birkeland et al., 2021);
- National statistical agencies (Central Statistical Bureau of Latvia, Ministry of Trade and Integration of Kazakhstan);
- Reports from transport operators (LDz Cargo,2023; KTZ Express, 2025);
- Intergovernmental memoranda and agreements (European Commission, 2019).

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2025 Volume 13 Number 2 (December)
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For contemporary digital aspects, data and reports on the implementation of electronic logistics platforms, port infrastructure digitalization, and the development of "green" and multimodal corridors were also utilized (European External Action Service (EEAS), 2022; Moisé & Sorbello, 2022).

4.3. Selection criteria and analytical indicators

The study applies the following criteria and indicators, drawn from international practices (Muratova et al., 2023; Metera, 2022):

- Total and sectoral trade turnover (in euros and dollars), including annual and five-year dynamics;
- Export/import structure by product categories (metals, agricultural products, petroleum products, pharmaceuticals, IT services);
- Diversification coefficients (for example, calculated using the Herfindahl-Hirschman Index – see Muratova et al., 2023);
- Share of services (logistics, transport, digital) in the composition of foreign trade flows;
- Institutional parameters: number and nature of agreements, participation in international initiatives, degree of digitalization of procedures (Birkeland et al., 2021; European Commission, 2023);
- Key transport infrastructure indicators: port throughput capacity, cargo volumes, processing speed, share of multimodal transportation (Middle Corridor, 2022).

For the first time, quantitative indicators were used to assess digitalization, including the implementation of electronic document management, cargo processing times, and the volume of container shipments utilizing electronic platforms (Moisé & Sorbello, 2022).

4.4. Methods of empirical and comparative analysis

Quantitative analysis is conducted based on official foreign trade data, employing methods such as averages calculation, growth rate assessment, concentration indices, and dynamics of flow structure (Observatory of Economic Complexity (OEC), 2024; Muratova et al., 2023; Akhmetkali, 2023).

Additionally, the following methods are used:

- Comparative Institutional Analysis – to compare the evolution of bilateral relations between Kazakhstan and Latvia with that of other Baltic countries, as well as to identify differences in institutional cooperation models and the management of logistics and energy flows (Birkeland et al., 2021; Metera, 2022; Khitakhunov, 2023; Gulomova, 2023; Harutyunyan, 2022).
- Case Study Analysis – to reveal the specifics of implementing major infrastructure, investment, and digital projects (port development, adoption of electronic platforms, intergovernmental initiatives), as well as to analyze the impact of macroeconomic and political shocks (COVID-19, sanctions, geopolitical turbulence) (Moisé & Sorbello, 2022).
- Content Analysis – to study regulatory acts, agreements, EU and Kazakhstan work programs, company and government press releases (European Commission, 2019).
- Network and Political-Geographical Analysis – to explain Latvia's specific role as a "logistics gateway" and intermediary between Kazakhstan and the EU, including the assessment of infrastructure nodes, transport routes, and digitalization strategies (Birkeland et al., 2021).

4.5. Procedure for comparison and verification of results

To enhance the reliability of the conclusions:

- Data from various statistical systems (EU, Kazakhstan, UN COMTRADE, OEC) are compared – any discrepancies are analyzed and interpreted according to a unified methodology (Omirgazy, 2024; Observatory of Economic Complexity (OEC), 2024; Khitakhunov, 2023);
- Cross-validation is performed: findings on dynamics, structure, and institutional changes are corroborated by multiple sources simultaneously – including scholarly publications, EU reports, and materials from Kazakhstan and Latvia (European Commission, 2019; Akhmetkali, 2023; Muratova et al., 2023).

4.6. Limitations and assumptions

Not all types of services and digital solutions are fully reflected in official statistics, and some data on new logistics platforms and "green" corridors remain preliminary (European External Action Service (EEAS), 2022).

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
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There are discrepancies in the methods of accounting and data publication between the EU and Kazakhstan (Metera, 2022; Khitakhunov, 2023). Certain areas, such as innovative investments and internal corporate strategies, have been studied primarily through case examples and may require further validation as new open data become available.

5. Research Results

This chapter presents the outcomes of a structural, institutional, and infrastructural analysis of the trade and economic relations between Kazakhstan and Latvia during 2021–2023. Unlike the descriptive dynamics outlined in Chapter 3, the main focus here is on interpreting the identified trends and explaining the "mechanics of success" through digitalization, institutional arrangements, and new logistics corridors.

First and foremost, it should be emphasized that the institutional and infrastructural gains achieved in the cooperation between Kazakhstan and Latvia are largely driven not by independent strategic decisions of the Latvian side, but by its integration into pan-European logistics and digital platforms (Boonstra et al., 2019; Boute, 2020). Acting as the "Eurasian gateway," Latvia relies on the normative and investment framework of the European Union, which enables the country to offer competitive transit conditions and seamless interaction.

This status makes the Latvian route particularly attractive for Kazakhstan as a pragmatic yet derivative instrument for accessing EU markets within the overall strategy of the European Union, rather than as a result of Latvia's own foreign economic initiatives.

5.1. Next-generation logistics and institutional effects

To accurately assess the impact of institutional and logistical reforms, it is essential to analyze the structural shifts that drive them. The qualitative shift in logistics flows between Kazakhstan and the EU is due to Latvia's role as a functional component of the pan-European infrastructure. Its position as the "Eurasian gateway" is a direct result of its systemic integration into EU initiatives and multilateral transport corridors like TITR and TRACECA. The 68% growth in trade turnover between Latvia and Kazakhstan highlights Latvia's institutional and technological advantage in the region. This is confirmed by the fact that its growth rates surpass those of Lithuania (26%) and Estonia (15%) (Muratova et al., 2023). This effect is directly linked to investments in digital infrastructure, such as e-Customs Latvia and SmartPort Riga. These solutions have created a seamless logistics environment, reducing the average cargo processing time from 48 to 28 hours and increasing the share of electronic export processing to 61% (Birkeland et al., 2021). These indicators show that digitalization is a key factor in ensuring efficient and reliable interaction between the two countries.

5.2. Diversification and technologization of exports

An assessment of the export structure from Kazakhstan to Latvia reveals tangible changes in the pattern of interaction between the two countries. The shift in the sectoral profile of exports reflects the outcomes of national strategies and the operation of new logistics chains – we observe how the portfolio of exported goods becomes more complex, while dependence on raw materials declines.

The data demonstrate not only the dominance of metallurgical products but also a significant increase in shipments of non-raw goods, including agricultural products, fertilizers, and machinery. The growth of the "Others" category signals diversification and increased complexity of Kazakhstan's production base and reflects the effectiveness of cooperation with Latvia in establishing logistics and technological "gateways" to the EU market (Gereffi, 2020; Nakhle, 2023), as shown in Table 2.

5.3. Import from Latvia: Focus on technology and innovation

The changing structure of Latvian exports to Kazakhstan serves as a direct indicator of integration quality: the higher the share of technological goods and IT solutions, the greater the institutional compatibility between the countries and their capacity to develop modern production chains.

The technologization of imports from Latvia strengthens Kazakhstan's position in the digital economy, supports the modernization of production capacities, and fosters the development of new industries. The significant share

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2025 Volume 13 Number 2 (December)
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of IT solutions and equipment signals Latvia's transition to the role of a supplier of intellectual and service products, rather than merely a transit country (Metera, 2022; Moisé & Sorbello, 2022; Miroudot & Nordström, 2020), as reflected in Table 3.

5.4. Digitalization and "smart" logistics corridors

To assess the depth of these transformations, it is important not only to record the shift towards electronic document management but also to analyze its tangible economic effects: acceleration of processes, increased containerization, and reduction of transaction costs.

Table 4. Dynamics of digitalization and logistics innovations in the EU (2021–2023)

Indicator	**2021**	**2023**	**Δ, %**
Electronic export processing (%)	38	61	+60.5
Average processing time (hours)	48	28	–41.7
Share of containerized transport (%)	24	31	+29.2

Sources: the authors' compiled based on the data from European Commission, 2023.

The growth in digitalization contributes to a sustainable reduction of time and financial costs in export/import operations, facilitates integration into EU supply chains, and enables Latvia and Kazakhstan to develop competitive advantages in the region. Institutional innovations are also evident in the expansion of joint forums, working groups, and blockchain pilot projects for cargo tracking (Saktaganova et al., 2025; Moisé & Sorbello, 2022).

5.5. Infrastructure and multimodal Projects: Zubr and Rail Baltica

The contemporary efficiency of Eurasian transport links is determined not only by cargo volumes but also by flexibility, digital density, and the capability to integrate different modes of transport into a cohesive logistics ecosystem. The assessment of infrastructure projects requires analyzing their contribution to throughput capacity, multimodality, as well as their potential for digital transformation and the resilience of regional flows.

Zubr project. The Zubr project is an integrated rail–sea service connecting Latvia, Kazakhstan, Ukraine, and China, creating synergy between railway and port capacities. Its main competitive advantage lies in flexible multimodal logistics, rapid adaptation to market fluctuations, and the deployment of digital platforms for cargo tracking and processing. As a result, Zubr has become not only an effective complement to the Trans-Caspian International Transport Route (TITR) but also an example of an innovative service enhancing the transit capabilities of the entire region (Middle Corridor, 2022; Muratova et al., 2023; Organisation for the Cooperation of Railways (OSJD), 2024).

Rail Baltica project. Special attention is warranted by the Rail Baltica project–the largest transport initiative of the European Union in the Baltic region, capable of transforming the architecture of Eurasian logistics chains. Rail Baltica serves as a strategic integration axis, linking Latvian ports with Central Europe and Central Asian countries (Karjalainen, 2022; RB Rail AS, 2024; Harutyunyan, 2022). The implementation of this project elevates Latvian hubs from national transit nodes to integral parts of a unified European and Eurasian infrastructure.

Key differences: While Zubr operates as a flexible, rapidly scalable multimodal service capable of adapting to changing flows – especially in containerized, agricultural, and machinery sectors – Rail Baltica is conceived as a long-term European-level megacorridor. Its objectives include not only radically increasing throughput and delivery speed but also ensuring "green" multimodality, digital integration, and full interconnection with TITR for expanded access to Kazakhstan and Chinese markets (Piterina & Masharsky, 2019).

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2025 Volume 13 Number 2 (December)
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The expected effects of Rail Baltica are summarized in Table 5 below.

Table 5. Impact of Rail Baltica on Eurasian Transit Parameters

Indicator	**Before Rail Baltica**	**After Rail Baltica (forecast)**
Delivery time Kazakhstan–EU (days)	12–16	7–9
Throughput capacity (TEU/year)	<150,000	>350,000
Containerization share (%)	28	52
Integration with TITR	Partial	Full
Kazakhstan grain export via Baltic States (thousand tons)	~300	>600

Sources: the authors' compiled based on the data from European Commission, 2023; RB Rail AS, 2024.

The deployment of Rail Baltica entails not just technological modernization but also institutional transformation of logistic processes in the region. It is anticipated to reduce transit times between Kazakhstan and EU countries to 7–9 days, more than double throughput capacity, and significantly increase containerization and the export volume of key commodities, primarily grain. Integration of Rail Baltica with TITR minimizes both logistical and administrative costs, facilitating "seamless" cargo movement between the EU and Central Asia (Prause, 2019; European Commission, 2023; RB Rail AS, 2024).

Thus, the Zubr and Rail Baltica projects stand as critical examples of synergy among innovation, digitalization, and institutional reforms. Their implementation not only strengthens Latvia's and Kazakhstan's positions in the Eurasian logistics system but also shapes the framework for sustainable development across the EU–Central Asia corridor. Together with digital platforms and institutional initiatives (TITR, TRACECA), these infrastructure megaprojects become the "growth points" that determine the region's long-term competitiveness.

6. Discussion of results

This chapter discusses the main findings and key factors influencing the development of transport-logistics cooperation and digital integration between Kazakhstan, Latvia, and the European Union. Special attention is given to institutional reforms, innovative digital solutions, and infrastructural projects that create new opportunities and challenges for the sustainability and efficiency of logistics corridors (Karjalainen, 2022; Andersone, 2024). The discussion is based on a comparison of empirical data with theoretical premises and aims at formulating practical recommendations to strengthen economic partnership across the Eurasian space.

6.1. Synergy of institutional reforms, gigitalization, and infrastructure projects

The analysis confirms that the modern model of cooperation between Kazakhstan and Latvia relies on a unique combination of institutional flexibility, proactive adoption of digital technologies, and reliance on large-scale infrastructure initiatives (Birkeland et al., 2021; European Commission, 2023; Saktaganova et al., 2025). Latvia exemplifies a "small state intermediary", effectively implementing a strategy of integration with the EU and Central Asia by developing ports, railway hubs, and digital platforms such as SmartPort Riga and Baltic Port Community System (PCS). Kazakhstan, in turn, leverages this window of opportunity for export diversification, enhancing the resilience of logistics flows, and adopting innovative services (Figueroa-García & Gélvez-Rubio, 2022; Muratova et al., 2023).

6.2. Competitive advantages and institutional effects

Latvia's leading role among the Baltic countries is secured not only by favorable geography but also by accumulation of institutional capital–active participation in the EPCA, TRACECA, TITR agreements, sustained engagement in multilateral formats, and the implementation of pilot digital and infrastructure initiatives

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2025 Volume 13 Number 2 (December)
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(Metera, 2022; Muratova et al., 2023; European Commission, 2019; Andersone, 2024). Latvian transport and digital infrastructure functions not merely as a transit channel, but as a testbed for new logistics solutions, facilitating growth in non-raw material and high-tech exports from Kazakhstan (Nakhle, 2023; Harutyunyan, 2022).

Crucially, Latvia's competitive advantages and dominant role in Eurasian logistics are not the product of an autonomous or independent foreign economic policy. Rather, these institutional effects and the enhanced significance of the Latvian route stem directly from its integration into EU transportation, digital, and regulatory systems. Latvia mainly operates as a functional EU infrastructure and regulatory channel whose opportunities for Kazakhstan depend on EU-wide decisions, the distribution of flows, and support from European institutions (Karjalainen, 2022). Thus, Latvia's "dual" role as mediator and conditional partner is primarily dictated by external politico-economic conditions and may shift depending on the EU's future eastern strategy.

6.3. Digitalization and "smart" logistics corridors

The transition to digital platforms, the growing share of electronic cargo processing, and the reduction of customs clearance times position Latvia and Kazakhstan as regional leaders in digital logistics. Implementation of electronic documentation, blockchain solutions, and IT platforms synergizes with infrastructural initiatives, minimizing transaction costs and enhancing operational transparency (Miroudot & Nordström, 2020; Saktaganova et al., 2025; Moisé & Sorbello, 2022). These developments lay the foundation for sustainable growth and the integration of new participants into Eurasian supply chains.

6.4. Infrastructural megaprojects and their long-term impact

The implementation of the Rail Baltica and Zubr projects enables the countries not only to scale physical cargo flows but also to introduce standards of "green" multimodality, digital integration, and institutional compatibility.

Rail Baltica enhances Latvia's transit potential by creating fast and reliable connections with Central Europe and EU markets, whereas Zubr exemplifies efficient, flexible multimodal logistics, demonstrating resilience against external shocks (Prause, 2019; Karjalainen, 2022; OECD, 2023; RB Rail AS, 2024).

6.5. Barriers, risks, and areas for improvement

Despite the achievements, significant challenges remain:

- Differences in standards and the lack of harmonization in customs procedures,
- Varied levels of digital maturity and insufficient integration among some IT systems,
- The need for further modernization of port and railway infrastructure,
- Enduring geopolitical and market risks requiring adaptive strategies and coordinated responses (European Commission, 2019; Birkeland et al., 2021; Andersone, 2024).

Nevertheless, the accumulated experience and rapid pace of institutional, digital, and infrastructure transformations enable Latvia and Kazakhstan not only to maintain but also to increase their significance as key actors in Eurasian integration. These countries serve as models for replication in other parts of the region, and their ongoing projects become benchmarks for new EU-Central Asia initiatives.

Looking ahead, the further development of Latvian-Kazakh cooperation, as well as the stability and resilience of transport corridors, will depend not only on national strategies but also on priorities set by the European Union. Kazakhstan would be prudent to support flexibility and diversification of export routes, given that Latvia's institutional advantages will persist only with stable backing and integration within pan-European transport-logistics initiatives. In this context, the long-term positioning of Latvia as a key logistics and digital hub remains sustainable only with continued EU support and Kazakhstan's adaptive export route policies.

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7. Conclusion

The conducted study has provided a comprehensive analysis of the transformation of the economic and institutional partnership between the European Union and Kazakhstan, as well as identified the unique role of Latvia as an intermediate logistical and politico-institutional link within the emerging architecture of Eurasian connectivity.

The results of the analysis confirm the initial hypothesis that, amid a changing geo-economic environment–including the crisis of traditional transit routes, the growth of the EU's strategic autonomy, and Kazakhstan's diversification policy–a qualitative transition is occurring from declarative forms of partnership to instrumental integration. The substantial increase in trade turnover, the development of the TITR corridor, and Latvia's involvement in the EU's strategic initiatives indicate a genuine convergence of interests and enhanced resilience of Eurasian logistics chains.

The scientific novelty of this work lies in examining the EU–Kazakhstan interaction not only through the "center–periphery" dichotomy but also through the prism of regional intermediation, using the Latvian case as an example. For the first time in academic literature, an attempt is made to interpret Latvia's case as a catalyst for coupling EU policy in Central Asia with the practical logistics and institutional implementation of major infrastructure projects.

The practical significance of the study manifests in the formulation of proposals for developing transport-digital corridors, eliminating institutional barriers, and strengthening investment cooperation. These findings can be utilized in strategic planning of EU programs (Global Gateway, NDICI) and in Latvia's national foreign economic policy.

Prospects for further research include:

- Conducting empirical analysis of the efficiency of Latvian logistics hubs within the EU–Central Asia supply chains;
- Quantitative assessment of investment participation by Latvian and European institutions in Kazakhstan;
- Comparative study of the roles of other small EU countries (e.g., Lithuania, Czechia, Finland) in the strategy of integration with Central Asia.

At the same time, it is important to emphasize that Latvia's unique role in Eurasian logistics and institutional chains is fundamentally not the result of autonomous policy or strategic independence. All key infrastructural and institutional advantages of Latvia derive from its deep integration into European Union systems and depend on pan-European decisions, investment priorities, and the EU's logistics architecture. In this context, Latvia functions as a practical channel and infrastructural platform for realizing Kazakhstan's interests in the European direction, rather than as an autonomous actor in regional politics. The prospects for further strengthening Latvian-Kazakh partnership are directly influenced by the dynamics of the EU's foreign policy and strategy toward Central Asia.

The EU–Kazakhstan institutional and logistics partnership is entering a new phase where Latvia can and should act not only as a transit territory but also as an independent subject of Eurasian integration dynamics.
Practical recommendations:

- Intensify the implementation of unified digital standards for document flow (in particular, through expanding the electronic data exchange platform between Latvia and Central Asian countries);
- Initiate the development of a unified EU regulation for harmonizing customs clearance normative procedures;
- Support projects aimed at modernizing Latvian transport hubs linked to TITR within the frameworks of Global Gateway and NDICI programs;
- Ensure systematic assessment of the resilience of infrastructure nodes against geopolitical and logistical risks.

Thus, the cooperation model developed in this study not only addresses current challenges in global logistics but also lays a foundation for continued scientific and practical integration of the Eurasian space.

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EMOTIONS AND THEIR IMPACT ON THE BRAND: A NEUROSCIENTIFIC ANALYSIS OF TRUST AND SOCIAL MEDIA CONTENT SHARING IN GENERATION Z *

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Abstract. This study intends to use neuroscience tools such as eye tracking and facial expression analysis to further explore Generation Z's emotional responses to negative stimuli on social media. Particular emphasis is placed on negative emotions such as anger, contempt, fear, sadness and disgust and their impact on brand trust. The main objective of the research is to analyze how negative user-generated content (UGC) affect users' emotions, trust, and willingness to share content while also examining brands' strategies for responding to this content. With the increasing importance of digital marketing, understanding these emotional responses is crucial for brands to refine their online communication strategies and strengthen consumer trust. The findings of our study indicate that brand feedback does not mitigate the impact of negative emotions from negative UGC. Although most negative emotions did not have a statistically significant impact on trust and intention to share a post, we found that when it comes to trust, there is a noticeable mitigation of the impact of negative emotions. The emotion of disgust was significant for intent to share, and we observed a strong positive relationship between trust and intent to share the post further.

Keywords: user-generated content (UGC); brand trust; content sharing; emotion; digital marketing; social media; neuroscience analysis; eye tracking, FaceReader

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JEL Classifications: M31, M37, D83

1. Introduction

Sustaining business success depends on an organization's ability to understand consumer behavior trends and use them (Xiang et al., 2015) to its advantage. In the current fast-paced digital environment, businesses must leverage digital marketing strategies to effectively engage with their target audiences (Tarabasz, 2024). The

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2025 Volume 13 Number 2 (December)
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advancement of digital technologies such as social media, smart mobile technologies, cloud computing, and the Internet of Things has changed the way individuals conduct their daily activities (Alruthaya et al., 2021). Digitization has become a mega trend (Štefko et al., 2021), and technology has simplified the way organizations connect with their customers and clients using digital channels and language (Duffett & Marauele, 2024).

Social media is ubiquitous, widely used and culturally relevant. Given the enormous potential audience that spends a lot of time daily using social media on various platforms, it is not surprising that marketers have adopted social media as a marketing channel (Appel et al., 2020; Mugunzva & Manchidi, 2024). The emergence of social media has had a significant impact on how people communicate and socialize. Many people use social media to create and maintain social connections with friends and build their reputation (Jang et al., 2015). Social networks are currently helping with e-commerce thanks to digitalization, of which social commerce is a subset, carried out through social networks (Hajli et al., 2017). There is even a group of people who have not experienced life without the Internet. We are talking about Generation Z (Gen Z), or digital natives, for whom digital technologies have become an essential part of the daily routine (Alruthaya et al., 2021). The rise of social media and its significant impact on consumer behavior and marketing practices has largely been shaped by the platforms themselves. People around the world use social media in various forms (e.g., news feeds on Facebook and Twitter, private messaging on WhatsApp and WeChat, and discussion forums on Reddit) for several purposes. More recently, platforms such as Instagram and Snapchat have come to the fore, emphasizing images and videos over text (Appel et al., 2020). Nastišin et al. (2024) point out that visual content, specifically videos and photos, has a stronger impact on triggering user reactions compared to text posts and links, highlighting the importance and effectiveness of using visual media to engage and capture the audience's attention. Instagram, in particular, is growing in popularity among young people, reaching 1.5 million users in 2020, 32% of whom are young people in emerging adulthood (Sebokova & Filipcikova, 2021). According to the study by Lenghart and Leskova (2023), for Generation Z in Slovakia, the most popular social networking platform is YouTube, followed by Facebook and Instagram, which are ranked third. When it comes to text formats such as posting posts, blogs, comments, and statuses, Instagram emerged as the most used platform, as well as visual formats such as photos.

The rapid evolution of consumer behavior in the digital age presents both opportunities and challenges for marketers. As Tupikovskaja-Omovie and Tyler (2021) highlights that rapid changes in digital consumer behavior, influenced by the exponential adoption of smartphones, require timely and sophisticated responses from retailers to meet consumer needs. Nowadays, social networks are increasingly being used for purchasing decisions. Hudson et al. (2016) report that marketers are therefore adapting their strategies to reach more and more consumers and are placing greater emphasis on capturing consumers' attention on social media to encourage customer engagement. To effectively manage their reputation using e-marketing tools, organizations must consistently adhere to key principles, including prioritizing customer needs, ensuring top-notch quality, and continuously innovating their communication channels. Special emphasis should be placed on delivering high-quality content, as it plays a pivotal role in shaping public opinion in the online space, thereby directly affecting the organization’s image (Štefko et al., 2021). In 2020, Appel et al. (2020) reviewed the future direction of social media marketing and highlighted critical areas for further research, noting the importance of understanding the side effects of distrust of social media. They highlighted the impact that distrust of platforms can have on the credibility of content, including brand information and user-generated content.

There is an ongoing discussion about the social media activities of brands and companies. Some researchers believe that social media provides a unique opportunity for brands to foster customer relationships, while others believe otherwise (Laroche et al., 2013; Išoraitė, 2024; Ivančík et al., 2024; Msosa et al., 2024).

Laroche et al. (2013), Godey et al. (2016), and Hudson et al. (2016) state that there is currently little evidence on how social media marketing activities influence brand value creation and consumer brand behavior. The study by Godey et al. (2016) and Konečný et al. (2024) suggests that social media marketing efforts have a significant positive impact on brand equity and on two main dimensions of brand equity: brand awareness and brand image.

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2025 Volume 13 Number 2 (December)
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Another highly discussed marketing tool is user-generated brand content (Mayrhofer et al., 2020). User-generated content (UGC) refers to any text, data or activities created by users of online digital systems, shared and distributed by users themselves through independent channels. This content generates expressive or communicative impact, either alone or in combination with other contributions from the same or different sources (Santos, 2022). Kim and Johnson (2016) highlight that positive UGC related to a brand is essential to the brand because it stimulates eWOM (electronic word-of-mouth recommendation) type behaviors in consumers while promoting customer engagement and contributing to the growth of brand sales. On the other hand, Bigné et al. (2023) point out that negative UGC may discourage consumers from using a particular product or service, thereby creating a risk to brand reputation.

These findings on the impact of UGC are closely related to the concept of cause-related marketing (CRM), which is one of the most versatile activities within Corporate Social Responsibility (CSR) initiatives (Bhatti et al., 2023). CRM is a marketing strategy in which brands link their products or services to the promotion of socially beneficial causes. In this way, CRM not only improves corporate image but also positively influences consumer attitudes towards the brand (Badenes-Rocha et al., 2021). The combination of UGC and CRM can have a synergetic effect when users create content that supports a brand's CSR activities. When consumers share positive experiences with a brand that supports socially beneficial goals, this content can further strengthen the credibility of the brand. Conversely, negative reactions to inauthentic or poorly implemented CSR activities can lead to the spread of negative UGC, damaging the brand's reputation. Therefore, it is crucial that CRM initiatives are set up correctly and aligned with the values of the target audience to promote positive user-generated content and minimize the risk of negative UGC.

This experimental study focuses on the effects of negative user-generated content (UGC) on brand trust in a Generation Z social media environment. It examines how negative UGC and companies' reactions to this content affect users' attitudes and behaviors on Instagram. A fictitious social network advertising posted by a fictitious company selling SMART products was tested. At the same time, this post contained a description of a negative user comment and the company's reaction. The individual stimuli were designed to allow for the exploration of subconscious and conscious reactions to the brand's crisis communication. The study examines consumer reactions to social media content using two primary methods. The first group are neuroscience tools such as eye-tracking and facial expression analysis. Lim (2018) highlights that these tools are particularly valuable because they reveal insights that are usually hidden - they allow direct access to neural responses without the need to explicitly ask about respondents' thoughts, emotions, or decision-making processes. The second tool used is a questionnaire, which serves as a complementary method to neuroscience measurements. According to Vences et al. (2020), the combination of objective and subjective measurements is important to obtain a comprehensive picture of consumer reactions.

Recent research has increasingly focused on the role of digital transformation and decision-support systems in tourism, healthcare, and media, highlighting their socio-economic and managerial impacts. Gavurova et al. (2025) developed a hybrid decision-support model to assess the socio-economic effects of digital transformation in tourism, while another study by Gavurova and Polishchuk (2025) proposed a fuzzy set-based system to enhance travel planning for people with disabilities, demonstrating the inclusivity potential of digital tools. In the area of digital media, Moravec et al. (2025) examined algorithmic personalization and its implications for knowledge gaps and media literacy, which is closely related to public trust and digital communication. Complementary findings by Gavurova et al. (2024) emphasized the importance of information-analytical systems for evaluating automated news content, further linking digital transformation with media literacy. In the healthcare context, Smolanka et al. (2024) addressed the challenges of integrating IT solutions in healthcare institutions, and Gavurova et al. (2024) proposed an intellectual model for analyzing patient trust in medical staff, illustrating how digital systems can strengthen confidence and transparency in primary healthcare. In addition, Skare et al. (2023) presented a large-scale decision-making model for evaluating tourism infrastructure funding, reinforcing the practical significance of digital transformation in public decision-making processes. Collectively, these studies demonstrate that the intersection of digital technologies with tourism, healthcare, and media creates new frameworks for socio-economic development, public trust, and inclusive decision-making.

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2025 Volume 13 Number 2 (December)
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This study contributes to the understanding of how different forms of content, including negative UGC, affect trust and brand loyalty. It also examines how effective brands' responses to this content are and their impact on consumers' overall perceptions. These insights are essential for building sustainable digital marketing strategies that take into account the specific needs of Generation Z.

2. Formation of research hypotheses

As mentioned above, in the current digital age, social media plays a key role in the communication between brands and consumers. An essential part of digital marketing is customer reviews and statements about products or services, which significantly influence consumer decisions and satisfaction levels. The role of these reviews in digital marketing is undeniable. Through digital marketing, many customers make repeat purchases online, and their reviews provide information about the satisfaction levels of their loyal customers. Reviews help the other person decide whether to buy or not (Vanitha & Anuradha 2024). They are also critical data that have a significant impact on product sales (Garg et al., 2022). Through various platforms, brands can not only showcase their products but also actively form relationships with customers, build trust and increase loyalty (Bhatti et al., 2023). This dynamic is particularly visible in the context of user-generated content (UGC) and Corporate Social Responsibility (CSR) initiatives, which can promote credibility and positive brand perception but can also have the opposite effect, i.e., distrust and negative brand perception.

CRM, as a specific tool linked to CSR, enables brands to connect their products or services to socially beneficial goals. This approach can improve corporate image and positively influence consumer attitudes towards the brand (Badenes-Rocha et al., 2021). Negative emotions that arise from inappropriately implemented CSR initiatives or from a brand's inadequate response to criticism can increase the risk of spreading negative UGC, which seriously damages the brand's reputation. We suggest that an important strategy to mitigate the negative impact is a brand backlash to negative content. This response can not only mitigate negative emotions but also improve brand trust and foster customers' intention to share brand-generated content. Based on the above findings, the following hypotheses were formulated:

H1: Brand backlash mitigates the impact of negative emotions triggered by posts that contain negative content.

We hypothesize that brand backlash to a negative comment will mitigate its impact on respondents' emotions. The irrational behavior is based on consumer safety, where despite the influence of culture, etc., importance has been and still is given to attributes such as awareness, certification, origin, quality, etc. (Wang et al., 2018). It is irrational beliefs that can play an important role in cognitive evaluation (David et al., 2002). Since the habituation effect may have occurred in our study, where Thompson and Spencer (1966) formulated the first basic formal definition of this phenomenon, the habituation effect may thus cause a reduction in responses in repeated simulation.

H3: Brand response reduces the negative impact of emotions triggered by posts with negative user-generated content with the intention to share brand-generated content.

Social networks are one of the most effective tools for connecting products with potential customers today. Social networking platforms provide a means for social interaction and allow brands to connect with consumers on a deeper level, building trust and loyalty (Sajid, 2016). As Štefko et al. (2021) state, social networks provide an opportunity for service providers and sellers to utilize recommendations from family and friends as an effective marketing tool. This theme is echoed by Appel et al. (2020), who highlight that distrust of social media platforms can negatively affect the credibility of content shared by brands, including user-generated content (UGC). Customer engagement has been recognized as a fundamental determinant of brand loyalty (Li et al., 2020). The results of Badenes-Rocha et al. (2021) show that the more time is spent looking at a company's reactions to negative user-generated content, the more the relationship between trust and consumer advocacy towards the company weakens. Research by Sharma and Klein (2020) confirmed that engagement is key to online shopping; this study uses consumer perceived value, perceived trust, and susceptibility to interpersonal influence to provide further insight into consumer intention to participate in online group buying.

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2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/p4562938953

User-generated content (UGC) drove higher purchase intent than published ads and brand posts. Increased user attention reduced negative reactions to UGC compared to brand posts. The study suggests that while branded messages on social media activate users' awareness of persuasion, user-shared content can persuade without increasing this awareness. Stricter regulations are recommended to ensure transparency, including disclosure requirements for UGCs involved in promotional campaigns to protect consumers from hidden advertising practices (Mayrhofe et al., 2020). These issues are particularly key in the Generation Z environment, which is heavily influenced by visual and emotional stimuli on social media. Authors Hudson et al. (2016) surveyed consumers in France, the UK and the US and compared those who interact with their favorite brands via social media with those who do not. Findings showed that social media use was positively related to the quality of the relationship with the brand, and the effect was more pronounced for perceptions of high anthropomorphism (the extent to which consumers associate human characteristics with brands).

H2: Negative emotions from posts with negative user-generated content (UGC) are less likely to affect brand trust when brand feedback is present.

Creating trust and interactions is the foundation of effective customer engagement with a brand. Li et al. (2020) highlight that brand loyalty can be built through customer engagement, with trust and brand attachment playing a key role. Qin (2020) adds that brand-consumer interactions are influenced by consumers' motives, such as information-seeking and self-identity reinforcement. These motives influence users' behavior, whether in consuming content or creating it.

Perceived interactivity and engagement are important factors in building brand trust, as supported by a study by Samarah et al. (2022) showing a positive association between customer engagement on social media, brand trust and loyalty. However, negative content can disrupt these relationships. Badenes-Rocha et al. (2021) point out that a brand needs to actively respond to the negative emotions evoked by negative UGC to minimize its impact. Brand loyalty is one of the essential tools for any company to thrive in a highly competitive marketplace. A strong brand promotes a lasting relationship between consumers and producers (Ahmed et al., 2014). Laroche et al. (2013) confirm that brand trust has a mediating role in converting the effects of strengthened relationships in the brand community into brand loyalty. Ahmed et al. (2014) define brand trust as the assurance that a brand provides to its customers to meet their expectations. Brand trust plays a critical role in fostering customer loyalty; without it, customers are unlikely to cultivate a sense of brand loyalty. To establish trust, consumers must evaluate and verify the information provided about the product.

H4: Trust in brand-generated posts positively influences consumers' intention to share that content on social media.

According to the theoretical elaboration and pointing to various research studies, especially the aforementioned studies by Bigné et al. (2023) and Badenes-Rocha, Bigné, and Rouiz (2021), we have established the following concepts of analysis and individual hypotheses that focus on the behavior of the participants within the framework of our research questions. Bigné et al. (2023) focused on the influence of emotional and cognitive factors on decision-making processes, while Badenes-Rocha, Bigné, and Rouiz (2021) analyzed cultural and social differences in responses to marketing stimuli. These research approaches also helped us, in combination with the previous literature search, to formulate the above hypotheses.

3. Research methodology

The main aim of the research is to analyze how negative user-generated content (UGC) affect users' emotions, trust, and willingness to share content while also examining brands' strategies for responding to this content. The experimental research was carried out in Slovakia in the specialized Laboratory of Neuromarketing, which operates at the Faculty of Management, Economics and Business of the University of Presov. The research was carried out with the aim of clarifying the subconscious reactions of consumers to various visual and emotional stimuli while strictly observing the principles of neuromarketing research and ethical norms defined by professional standards. Each participant was duly informed about the biometric testing process, the reasons for

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/p4562938953

its implementation, and how their personal data would be processed and stored while ensuring maximum transparency of the entire process.

Participants received detailed information materials that provided them with an overview of the research objectives, the specific implementation steps and the measures taken to protect their privacy. Consent to participate in the research was expressed by a handwritten signature, which also confirmed their understanding of all relevant aspects. An important principle of the research was the anonymity of the participants, thus minimizing potential concerns about misuse of data and maximizing trust between the research team and the respondents. Data collection took place between 17 and 31 October 2024. Participants were informed in detail that they were taking part in a neuromarketing study designed to explore their unconscious responses, with an emphasis on analyzing their spontaneous emotional and physiological responses to different stimuli. The study of consumers' implicit emotions has always been described as a difficult and complicated mission. This approach has made it possible to collect valuable data that contribute to a better understanding of consumer behavior and preferences (Ismael, Ploeger et al., 2019; Gunaratne et al., 2019).

3.2 Research sample

The total research sample consisted of 141 respondents, of which 67 were male (47.52%) and 74 were female (52.48%), with a mean age of 21.04 years. The representation of males and females in the sample allowed for a balanced view of the responses of both genders, which is important for capturing variability in subconscious consumer responses. Equally, the average age of the participants was a useful factor for examining the behavior of a generation that is often considered a key target group in modern marketing campaigns. The sample was composed exclusively of students from the Faculty of Management, Economics and Business of the University of Presov, with 86 (60.99%) participants of Slovak and 55 (39.01%) of Ukrainian nationality. Table 1 provides a detailed description of the composition of the research sample by gender and age of the research participants.

Table 1. Research sample of participants

		Count (%)
Gender	Male	67 (47.52)
	Female	74 (52.48)
	Total	141 (100)
Year of birth	1999	2 (1.42)
	2000	14 (9.93)
	2001	25 (17.73)
	2002	25 (17.73)
	2003	35 (24.82)
	2004	20 (14.18)
	2005	11 (7.8)
	2006	9 (6.38)
	Total	141 (100)
Educational level	Bachelor	78 (55.32)
	Diploma	63 (44.68)
	Total	141 (100)
Nationality	Slovak	86 (60.99)
	Ukrainian	55 (39.01)
	Total	141 (100)

Source: own elaboration (2024)

Since the research was conducted on a sample of students, the age range is between 20 and 26 years. We are talking about the so-called Generation Z. The generation born between 1995-2009 when the Internet quickly became popular, is known as "Internet natives" (Duffet, 2020). These groups of consumers have specific characteristics. Generation Z grew up in a digital world and is distinguished by high digital literacy, rapid adaptation to new technologies, and a preference for authentic brands that share their values (Duffett, 2020; Francis, Hoefel, 2025). Organizations should embrace these traits and incorporate the uniqueness of this cohort into the development of more sustainable marketing communications (MC) to promote the values of diversity that are prevalent among young consumers (Duffett, 2020).

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/p4562938953

The selection of students from the Faculty of Management, Economics and Business was deliberate and made based on availability. The student samples were deemed appropriate and even necessary because they represent the primary target group for the advertising practices under study. The participants had a basic understanding of marketing, which may have contributed to their deeper understanding of the test stimuli and the experiment itself. This homogeneity of the sample in terms of education also reduced the variability caused by different academic backgrounds, thus strengthening the internal validity of the research.

3.3 Experimental design, procedures, and incentives

Research participants were presented with a post on the social network Instagram, published by WatchWorld, a fictitious company selling SMART products. The fictional Instagram fan pages, including brand-related UGC, were developed as visual stimuli and presented through an online questionnaire that we administered ourselves. This post provided information about the company's initiative, but a negative comment was posted underneath that had the potential to influence participants' perceptions. Following this initial display, an identical post was presented to participants, this time with the company's response to the negative comment. This pair of stimuli was designed to allow for the exploration of subconscious and conscious reactions to a brand's crisis communication. Each of the stimuli was presented to participants for 40 seconds. This exposure time was carefully calculated based on pre-testing conducted on a sample of seven participants. The aim was to ensure sufficient time to perceive the visual and content elements of the stimuli presented while allowing participants to immediately respond to the questions that followed each stimulus.

The stimuli were presented on a 24-inch PC monitor with 1920 x 1080p resolution, which provided the high-quality display needed for accurate tracking of visual responses. An advanced 60 Hz Smart Eye AI-X eye-tracker system, located directly on the monitor, was used to measure eye movements. This hardware allowed accurate analysis of gaze focus, time spent on individual post elements, and visual scanning dynamics. Eye tracking has wide application in digital marketing, where it serves as a valuable tool for analyzing consumer behavior (Tupikovskaja-Omovie & Tylerand, 2021) and helps optimize marketing strategies by better understanding customers' visual attention (Casado-Aranda et al., 2020; Azawai 2019) and decision-making processes.

The Logitech C980 high-resolution 1920 x 1080p webcam was used to capture surface facial emotions that reflect immediate emotional reactions to stimuli. This camera worked in conjunction with the AFFDEX software module integrated into the Imotions 10 platform, which allowed for detailed analysis of participants' facial expressions. The whole process was carried out on a PC with an Intel Core i5 processor, which provided sufficient power for real-time data processing. The Imotions 10 software included modules for both eye-tracking and emotion analysis, thus enabling synchronous evaluation of visual and emotional reactions to the presented stimuli. This integrated approach allowed for comprehensive data on participants' behavioral interactions with social posts containing crisis elements and brand responses.

Visual attention is a key metric in neuromarketing because it shows how a consumer interacts with visual stimuli (Royo-Vela & Varga, 2022). Two important metrics to measure attention are fixation duration (ms) and time to first fixation (ms). Fixation duration measures how long a participant's gaze remains on a particular visual stimulus. Longer fixation duration indicates a higher level of engagement or interest in the item. Time to first fixation reflects how quickly the participant fixates their gaze on a given element after the stimulus presentation begins. A short time indicates a high ability to attract attention (Capogna et al., 2021; Tzamaras et al., 2023). Other indicators are fixation counts, which are the sum of repeated glance times at the target region of interest, and dwell time, which reflects the brain's time to acquire and process information. Both are positively proportional to visual attention (Hwang et al., 2018).

The data on trust and intention to share were collected through Table 2 questions based on theoretical elaboration and other authors such as Majerczak and Strzelecki (2022); Hancock et al., (2023), Bigné et al. (2023); Hu and Noor (2024).

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/p4562938953

Table 2. Questionnaire items

	Cronbach's
Trust	0.722
I find the information shared by WatchWorld to be truthful and honest.	
WatchWorld is interested in the opinions of its customers.	
I think that WatchWorld has made its products from high-quality materials at a high technological level.	
Intention to share	0.739
I would also share WatchWorld posts on my social networks.	
I would also recommend the product to my friends and acquaintances.	
I would like to be part of the WatchWorld community based on their online communications.	

Source: own elaboration (2024)

Cronbach's alpha is a statistical indicator of the internal consistency of a measurement instrument, such as questionnaires or scales, and is used to assess the extent to which items within an instrument are homogeneous and related. The results of 0.722 and 0.739 indicate an acceptable and acceptable reliability result (Streiner, 2003).

Figure 1 shows the presented stimulus with the selected AOIs and the resulting attentional heat map of the research participants in the feedback stimulus.



Figure 1. Incentive with company feedback

Source: own elaboration (2024)

Figure 1 shows the stimulus, which includes the image/product, the company's contribution, the user's negative comment, and the company's feedback. The resulting heat map shows the areas where participants focused their attention the most, with the intensity of the colours visualizing the distribution of attention, which we will address when analyzing and comparing each AOI.

AOI is a concept often used in neuromarketing research to analyze visual attention using eye-tracking technology. AOI refers to specifically defined areas on a visual stimulus that are the focus of research interest. In our case, four areas of interest are identified (Table 3).

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/p4562938953

Table 3. Selected areas of interest (AOI)

AOI 1 WatchWorld's contribution: *more than just a watch, your personal trainer, assistant and health watchdog all in one! Track your health, stay in touch with your loved ones and let your wrist stand out. All in a premium design with top technology to make the most of your everyday life.*
AOI 2 Negative reaction/user comment: *another overpriced watch that pretends to be something special. You can find much cheaper ones on the market with the same features. I feel like we're just paying for the name here*
AOI 3 Picture of the product presented by the company.
AOI 4 Company's response to a negative user comment: *thank you for your comment. But our customers know that their quality and features bring a sense of security and comfort. This makes them an exceptional product for exceptional people.*

Source: own elaboration (2024)

Based on the stated research objectives, methodological framework and formulated hypotheses, regression analysis and analysis of the data obtained using eye-tracking technology were conducted. Regression analysis was used to uncover relationships between participants' behavioral or emotional responses to the presented stimuli as well as trust and intention to share. Eye-tracking analysis was applied to interpret participants' visual attention. Key metrics such as fixation duration and time to first fixation provided important data on which elements (AOIs) of the stimulus were most attention-grabbing and how participants visually processed the presented content.

4. Results

Since we examined negative UGC commentary, which is often highly sensitive and can affect brand perception and reputation, in conjunction with the emotions generated by it, both before and after the publication of the brand's response to the commentary, we focused only on negative emotions. In order to quantify its impact, we used the AFFDEX FaceReader for face reading (emotion) and eye-tracking (eye movement), which allowed us to track the attention and emotional reactions of respondents to the depicted post. The measurements of each emotion that respondents showed during the visualization of the experimental research are recorded in Table 4. We focused on negative emotions in relation to the company's reaction to a negative UCG comment from a customer or an Instagram social network user, and there was no reaction, i.e., no feedback from the company. We investigated the impact of negative emotions without CRM globally and in the presence of CRM. We found the variability as well as the intensity of emotions by plotting means and standard deviations.

Table 4. Descriptive statistics of the measured negative emotions during post-visualization

		Global (141)	Feedback	Without feedback
Anger	Average	0.285	0.298	0.273
	St. Dev.	0.408	0.417	0.399
Contempt	Average	0.684	0.807	0.562
	St. dev	1.850	2.274	1.426
Fear	Average	0.319	0.420	0.219
	St. dev	0.367	0.585	0.148
Sadness	Average	0.265	0.227	0.302
	St. dev	0.250	0.174	0.327
Disgust	Average	0.045	0.054	0.037
	St. dev	0.137	0.176	0.098

Source: own elaboration (2024)

The most dominant negative emotion is contempt, with a mean of 0.684 globally, 0.807 in the presence of CRM, and 0.562 in the absence of CRM. The second strongest emotion is fear, which, like contempt, is higher in the presence of the company's CRM. This is followed by the emotions of anger and sadness, with sadness being the

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/p4562938953

only emotion that came out slightly stronger without feedback, which may indicate an emotional response to feeling unsupported or uninformed. The weakest expressed emotion is disgust, which is negligible compared to the other emotions. Given this, *we reject hypothesis H1, which claims that brand feedback mitigates the impact of negative emotions elicited by posts that contain negative content.*

Table 5. Regression analysis of the impact of negative emotions on consumer brand trust before and after brand feedback on negative UGC comment

	Relation	Standardized β	t-statistics	Sig.
Before feedback	Anger -> Trust	0.091	1.081	0.282
	Contempt -> Trust	-0.111	-1.313	0.191
	Fear -> Trust	0.151	1.799	0.074
	Sadness -> Trust	0.092	1.091	0.277
	Disgust -> Trust	0.079	0.939	0.349
After feedback	Anger -> Trust	0.059	0.692	0.490
	Contempt -> Trust	-0.051	-0.606	0.545
	Fear -> Trust	0.141	1.681	0.095
	Sadness -> Trust	0.110	1.300	0.196
	Disgust -> Trust	0.041	0.478	0.633

Source: own elaboration (2024)

Table 5 shows us the effect of emotion on trust before and after giving some form of feedback. Specifically, we focused on the effects of negative emotions, namely anger, contempt, fear, sadness, and disgust. Regarding the results of the regression analysis, before feedback was given, only one emotion showed a negative impact on trust, namely contempt; all the remaining emotions showed a positive impact on trust, with disgust having the weakest impact, followed by anger and sadness. However, none of the emotions showed a statistically significant impact. The more interesting finding highlighted to us is that of fear, which showed a borderline of statistical significance. Although not statistically significant, the finding in question deserves more attention. Regarding the reactions after the CRM comment was made, as with the non-CRM reactions, neither emotion showed a statistically significant effect on trust. However, we did detect differences, namely a reduction in the influence of anger, contempt and disgust, with fear retaining a slight positive influence. The impact of sadness on trust increased, which can be noticed by quantifying it with $\beta = 0.109606$. Although the β value indicates a potential subtle effect, overall, it is not strong enough to be considered statistically significant. We find that although negative emotions did not show a significant effect on trust in the situation without or with the presence of CRM, and thus *reject H2, we can see a subtle mitigation of the effect of negative emotions on trust after CRM, with the exception of sadness*.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/p4562938953

Table 6. Regression analysis of the impact of negative emotion on intention to share a post before and after brand feedback on a negative UGC comment

	Relation	Standardized β	t-statistics	Sig.
Before feedback	Anger -> intention to share	-0.115	-1.362	0.175
	Contempt -> intention to share	-0.146	-1.743	0.084
	Fear -> intention to share	0.032	0.380	0.705
	Sadness -> intention to share	-0.086	-1.012	0.313
	Disgust -> intention to share	0.017	0.204	0.838
After feedback	Anger -> intention to share	-0.117	-1.391	0.166
	Contempt -> intention to share	-0.060	-0.709	0.480
	Fear -> intention to share	0.069	0.818	0.415
	Sadness -> intention to share	-0.105	-1.240	0.217
	Disgust -> intention to	-0.193	-2.321	0.022 *

Source: own elaboration (2024)

Overall, the emotion of disgust has the weakest effect on the intention to share, followed by fear, both of which show a positive effect. The emotions of anger, contempt and sadness showed a negative influence, with sadness showing the weakest influence. The impact of negative emotions on the intention to share a post before feedback was not statistically significant for any of the negative emotions. Of note is the emotion of contempt, which, although not statistically significant, would be well worth focusing on analyzing more in the future in terms of significance (p=0.08). Regarding the intention to share after the posting of the CRM by the company to the post, we can note that the emotion of disgust was statistically significant (p=0.022), which means that a higher level of disgust is significantly associated with a lower intention to share the content.

Table 7. Regression analysis of the impact of brand trust on the intention to share a post

Relation	Standardized β	t-statistics	Sig.
Trust -> Intention to share	0.336	4.206	4.64e-05 ***

Source: own elaboration, 2024

A strong, positive effect on the intention to share a post can be observed for trust, as can be seen in Table 7, where the results show that the higher the trust of users, the higher the likelihood that they will share the content. It is the low p-value ($p < 0.0001$) that suggests that trust can be considered a key factor that influences the intention to share content on social networks in online spaces.

Regression analysis provided key results regarding participants' emotional responses, their trust in the brand, and their intention to share. Hwang et al. (2018) reported that eye tracking provides valuable real-time information about consumers' potential and their visual behavior. The combination of statistical and eye-tracking techniques provides a comprehensive view of research participants' behaviors and responses, so we highlight selected results from eye-tracking for the stimulus we present. In the first step of analyzing the eye-tracking metrics, we focused on the first fixation in attention on the AOI Image (product) and AOI Text (all comments together without company feedback).

Table 8 shows the result of the Mann-Whitney U test in the differences in the duration of participants' average first fixation on AOI Text and AOI Product.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/p4562938953

Table 8. Comparison of AOI Text and Product – Duration of First Fixation

	Mean	Sum of Ranks	Mann-Whitney U	Sig. (2-tailed)
AOI Text	155.51	21927.00	7965.000	0.004
AOI Product	127.49	17976.00		

Source: own elaboration, 2024

Table 8 provides interesting results, where the first fixation time was longer for the text itself (155.51 ms) than for the visual image/product (127.49 ms). The result comes out statistically significant at $p \leq 0.05$ significance level. In general, research tends to find that visual stimuli attract more attention and acquire longer first fixation times than text (Gheorghe, et al., 2023; Klein et al., 2020). On the other hand, textual information can be perceived as important if it is relevant or contains critical information that the participant needs to process in order to understand the context or meaning. This may prolong the first fixation on the text; as Henderson, Ferreira (1990) point out, textual stimuli require more cognitive resources for their full comprehension. When reading a text, the participant is expected to analyze the content, which can lead to a longer duration of first fixation when trying to process individual words and sentences.

In the case of comparing individual AOIs in a stimulus without and with feedback, we assume the presence of habituation. Habituation in neuromarketing refers to a psychological process in which repeated exposure to a particular stimulus leads to a reduced response to that stimulus (Bartków et al., 2023). In the context of neuromarketing, it is a phenomenon that explains why consumers may initially respond strongly to an advertisement, product or content, but their interest decreases after repeated exposure to that stimulus. This process has a significant impact on advertising effectiveness and consumer engagement (Jankowski, 2021; Uribe-Bahamonde et al., 2019).

In our context, the stimulus was exposed twice in a row with a single change, whereas in the first exposure, there was no company feedback and in the second exposure, the same stimulus contained company feedback.

Table 9. Comparison of AOI with and without SV – fixation duration (ms)

	Mean	Sum of Ranks	Mann-Whitney U	Sig. (2-tailed)
AOI1 without SV	183.77	25911.00	3135.000	0.000
AOI1 with SV	91.22	12315.00		
AOI2 without SV	159.99	22558.00	6911.000	0.000
AOI2 with SV	119.58	16502.00		

Source: own elaboration, 2024

Table 9, unlike Table 8, presents the length of fixation per AOI. In both cases we observe statistically significant differences and this is probably due to the aforementioned habituation effect. Since the posts were presented twice in a row they did not meet the novelty condition and the participants already paid less attention to the individual post and the user's comment than in the first exposure.

An important aspect of the investigation is to compare the length of the fixation on the company's contribution, the user's comment and the company's feedback. In the above case, we consider the company's post and the user's comment observed for the first time in order to eliminate the habituation effect, which would make it impossible to compare the fixation length with the feedback seen by the participants for the first time.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/p4562938953

Table 10. Comparison of individual AOI with SV alone – fixation duration (ms)

	Mean	Sum of Ranks	Mann-Whitney U	Sig. (2-tailed)
AOI1 vs SV	117.15	16518.00	6507.000	0.000
AOI SV	164.19	22822.00		
AOI2 vs SV	94.05	13261.00	3250.000	0.000
AOI SV	187.62	26079.00		

Source: own elaboration, 2024

In Table 10, which shows a comparison of the three areas of interest (AOIs): the company post (AOI 1), the negative user comment (AOI 2), and the company feedback (AOI SV), all results are statistically significant, indicating that the fixation length was longer on the company feedback than on the post itself and the negative comment. This result suggests that research participants paid more attention to the company's response to the negative comment than to the company's original post or the negative comment itself. The longer fixation on the feedback may indicate that respondents were interested in how the company responded to the criticism.

In the context of marketing and online communication, how a company responds to negative feedback is important because it affects brand perception, transparency, and credibility. Consumers may perceive a negative comment as something that requires attention, but the actual response of the company may be considered more important because it provides information about how the company handles negative situations and how it tries to repair its reputation (Baumeister et al., 2001). The company's response may be perceived as crucial for brand transparency and credibility. People prefer transparent and quick responses to negative comments, which may be the reason why more time was spent on this feedback (Yuana & Sutarso, 2021).

Discussion and conclusions

The main aim of the research is to analyze how negative user-generated content (UGC) affect users' emotions, trust, and willingness to share content while also examining brands' strategies for responding to this content. Based on our results, we can conclude that although the impact of a negative comment (UGC) made by an Instagram platform user on a post depicted on the created account of a fictitious company, WatchWorld did not have a statistically significant impact on users' negative emotions after reading the post on the platform. Emotions such as contempt, fear, and anger showed the strongest intensity and variability; however, all three of these emotions showed higher variability and intensity after viewing the company's feedback in response to the user's negative UGC comment. This was followed by sadness, which was the only emotion that was stronger without the presence of the company's CRM comment, and the weakest emotion was disgust. Users experienced more negative emotions other than sadness when the company feedback to the negative UGC comment was present, which is also supported by the study of Bhandari and Rodgers (2018), who points out that the presence of company feedback to the negative comment, may exhibit signals that are perceived by users as a way of obscuring the product issue, thus suggesting that a company's response to a UGC user's negative comment may not have a mitigating effect on the emotions of the remaining users, but may amplify negative feelings. Below we will discuss the individual findings in more detail with respect to the hypotheses under investigation.

Trust

The results of our study showed that the effect of negative emotions in the presence of company feedback did not have a statistically significant effect on trust. However, changes before and after viewing the CRM post in response to the negative UGC comment suggest a subtle mitigation of the effect of emotion on trust. Just as Mian and Hattab (2013) say, interaction, communication and exchange of views deepen the relationship and trust is built on this. Consumers have trust in the brand, and hence, their willingness to buy increases (Habibi et al. 2014). trust is identified as one of the most significant barriers to e-commerce (Lin et al., 2017). Customer reviews, likes, comments, and communication with the seller build trust among potential customers (Sohn, Kim, 2020). Comments that are posted online have a positive impact, according to Weihong et al. (2022) have a great influence when it comes to consumers' purchase decisions, which is supported by the study of Bhandari and

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/p4562938953

Rodgers (2018), which showed that brand feedback has an indirect positive effect on increasing trust. No matter what type of issue is the subject of the negative UGC comment, it causes damage that is reflected in consumer trust (Wan et al., 2023). However, our results do not show the significance of the impact of negative emotions in the presence of feedback, which may be due to the fact that trust is influenced by various factors, with one of the reasons being the choice of the social network through which the post was published. Liu et al. (2022) point out that consumer behavior depends on trust in the online medium and the retailer. Since our company was fictional, it could have influenced consumers' trust in the company's published CRM comment.

Based on a thorough analysis, we can argue that effective digital marketing strategies must go beyond simply responding to negative comments. Companies should focus on building customer trust through personalized company responses and building and managing a strong community on social media.

Intention to share

The next objective of our study was to investigate the effect of negative emotions on the intention to share a published post after reading a negative UGC comment with and without social feedback. A statistically significant effect was found for the emotion of disgust, and this was after posting a company's feedback comment. Several authors have pointed out that negative feedback can damage a brand's reputation and influence consumer intention (Chevalier and Mayzlin, 2006; DeCarlo et al., 2007). Negative comment feedback can satisfy users' negative feelings, as Lin et al. (2017) point out consumers whose complaints have been defended and resolved alleviate their negative feelings. The study by Priluck and Lala (2009) also agrees with the statement that people are more satisfied after their problem is resolved, even if the failure has not occurred at all. This agrees with our results regarding the emotion of disgust, which came out as the only significant one. It was to resolve the situation that was mentioned in a negative comment about a fictional company's post published by an Instagram user, which increased the intention to share the post and decreased the users' feeling of disgust. However, the effect of emotion on the intention to share was not statistically significant in the remaining cases, which we attribute to the platform through which the post was published, as confirmed by the study of Bachleda et al. (2016), where they show a weaker impact of negative emotions on social media compared to other venues of posting a negative UGC paper in the online space, and this is compared to posting on review forums or directly on the company website.

Trust and feedback

The results of our study indicated that trust had a strong, positive effect on intention to share, which is supported by the study of Badenes-Rocha et al. (2021), where they pointed out that if a consumer has trust in a company, if they perceive the company to be honest and competent, this has an impact on the remaining users in their willingness to spread the positive word and their willingness to support its products which is in line with our results that testify that it is the users' trust in the company, i.e., in our case, trust towards the company with respect to the feedback, that led to a higher intention to share a given post further, thus confirming hypothesis H4. Feedback has a positive effect on trust in the company. Trust and purchase intentions increase in the presence of feedback, and according to Bhandari and Rodgers (2018), feedback has an indirect, positive effect on trust. Bigné et al. (2023) approached the implications of visual attention focused on negative UGC comments in posts and concluded that brand feedback reduces users' attention and focus on these comments. However, if they do focus on the comments in question, it reduces their trust and also their willingness to share, which is consistent with our results.

Emotions after reading the paper, eWOM in the case of Tuisku et al. (2017), were negative just after reading a paper published on an independent forum compared to the original store website. Comments posted on an independent forum cannot automatically be considered trustworthy; despite the untrustworthiness of the posted posts and the unprofessional nature of the information provided, reading these posts negatively affected participants' perceptions of the product. After the product evaluation, it was found that those who read the post on the independent forum rated the product lower, which attests to the results of our study, where negative emotions did not have as much influence as we predicted through sharing on the social network Instagram. If the post had been published on the company's website, we hypothesize that negative emotions might have shown a greater impact and could also be statistically significant in terms of the intention to share the post further. In our view, the weak effect of negative emotions on brand trust and intention to share has its origins in the choice

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/p4562938953

of product that was shared via the platform, namely smart watches, as pointed out by You et al. (2015) in their meta-analysis, where they revealed that the volume and valence elasticities of eWOM, where post and comment are included, vary and this varies depending on the nature of the product as well as the industry of the platform, as we mentioned above, based on which the effect of negative emotions on trust and intention to share that we originally predicted did not come out. Thus, our study findings highlight the importance of several factors compared to other studies, namely the nature of the product or the platform through which the post is shared.

Theoretical and Practical Implications

In the current digital era, social media, as a subset of digital marketing, represents a powerful tool for building relationships with consumers, interacting in real-time, and effectively influencing purchasing decisions, customer loyalty, and overall brand perception. Our study provides valuable insights into the intersection of negative emotions, brand trust, and digital marketing in the social media space. Our findings contribute to the literature on digital consumer behavior, online brand trust, and electronic word of mouth (eWOM) by expanding the understanding of how negative UGC influences emotional responses, trust, and content-sharing behavior on social media platforms. For service-based brands, such as those in tourism, financial services, healthcare, or telecommunications, the stakes are even higher due to the intangible nature of their offerings and the direct impact of customer experiences on brand perception.

Furthermore, the paper provides valuable practical implications. We recommend personalized and empathetic brand responses to negative UGC, through which companies should provide transparent solutions to the problems that have arisen. At the same time, use interactive customer engagement tools in the form of various surveys, Q&A, or live chats to strengthen consumer trust.

Limits and limitations of research

This study investigated how negative user comments affect brand perception (emotion, trust, and users' willingness to share content) among Generation Z. This study contributes to the understanding of the impact of negative emotions on brand perception. However, this research contains several limitations. First, the research sample included Gen Z but focused only on 18-25-year-olds; the research did not include younger respondents belonging to Gen Z.

We also take into account that some individuals belonging to Generation Z are still in the formative phase, a certain proportion is in the phase of entering the workforce, and only some of them are functioning in the sense of working with income (Benítez-Márquez et al., 2021). The entry into the market of young people belonging to this generation was greatly affected by the COVID-19 pandemic when unemployment among these young people grew (Sakdiyakorn et al., 2021). Second, the study sampled Slovak Gen Z respondents whose attitudes and behavior may differ from those of global Gen Z members. Future research could, therefore, focus on other parts of the world to gain a broader geographic and cultural perspective.

Another limitation is the focus on electronics only, specifically smartwatches, where people have just this kind of product in the online environment, according to Lin et al. (2003), high demands and expectations.

We also see the number of reviews as one of the limitations, as pointed out by Maslowska et al. (2017), who, in their study, investigated the impact of valence on consumer purchase behavior and intention and concluded that the impact of reviews also depends on the number of reviews. In our study, we only showed respondents one negative UGC comment, which was not relevant and thus did not have as much impact on the Instagram users who read the post as we expected. We recommend that in future experimental research of this form, we incorporate more comments, not only negative but also positive, where the power in each type of comment could be shown and as demonstrated, for example, by Wang et al. (2018), positive emotions have the greatest influence on consumer purchase decisions, followed by neutral and then negative emotions, which is reflected in our results.

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2025 Volume 13 Number 2 (December)
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INSTITUTIONS AND EMPLOYEE INTRAPRENEURSHIP: DOES GENDER MATTER?*

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Abstract. Innovation within an organization may depend on Intrapreneurship employee-related antecedents. This research draws upon institutional theory to investigate whether the external environment, in terms of formal or informal institutions, affects the likelihood of employee Intrapreneurship and to what extent gender can benefit from each side of institutions. Exploratory factor analysis and binomial logistic regression were applied to understand the relationship between institutions and employee Intrapreneurship among Genders. The findings conclude that organizations should proactively engage with and adapt to the formal institutional context to cultivate an intrapreneurial culture that encourages employee creativity, innovation, and entrepreneurial behavior. At the same time, gender plays a significant moderating role in establishing a robust connection between formal institutional factors and intrapreneurship. These findings can potentially develop intrapreneurship within organizations by tailoring the institutional environment accordingly.

Keywords: intrapreneurship; innovation; gender; institutions; Saudi Arabia

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1. Introduction

Researchers, practitioners, and policymakers continue to be interested in how the creation of something new from existing organizations by using synonymous words: Intrapreneurship, Intrapreneuring, Corporate Entrepreneurship, or Strategic Renewal (Kraus et al., 2019; Turro et al., 2020). Some authors have focused on how internal factors such as manager leadership style, organizational culture, or job design can impact employee Intrapreneurship (Badoiu et al., 2020; Kraus et al., 2018; Mustafa et al., 2018; Rigtering et al., 2019). Others have focused on external factors that have a relationship to employee Intrapreneurship, such as society rules (Elert and Stenkula, 2022), institutions and contexts (Bogatyreva et al., 2022), or the digital era (Wan and Liu, 2021). Taking as a whole, this esteemed work - whether focused on theory implications, organizational development, or policymaker facilitations - has created a foundation for this phenomenon. However, the theoretical models in corporate entrepreneurship recognize the significance of environmental factors, but there is a notable absence of quantitative studies investigating the precursors of Intrapreneurship within the context of developing countries or regions (Urbano et al., 2023). The previous literature remains somewhat focused on intrapreneurship in well-developed nations or compares it to developing nations. At the same time, the effect of external institutions on Intrapreneurship are still difficult to understand within emerging nations (Urbano et al., 2023). It is clear that Intrapreneurship is a developing topic, but it is less clear how Intrapreneurship activities work among genders and in a nation where the government heavily invests in empowering women to be in the

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workforce, such as in the case of Saudi Arabia (Aljarodi et al., 2022a, 2023). Contextual studies on the effect of formal and informal institutions within the entrepreneurship field in demand (Ivy & Perényi, 2020; Webb et al., 2020). A more profound understanding of intrapreneurship activity within a nation such as Saudi Arabia presents an understandable way to adapt to the fast-changing environment. It also should explain the influence of external institutions on each gender to be more creative and innovative employees. While there are some commonalities across investigating the influence of institutions on Intrapreneurship activity among gender (Chappell & Waylen, 2013; Turro et al., 2020), there are almost as many factors to investigate within institutions as there are influential in providing national theoretical and practical implications. While previous studies have examined the role of institutions in intrapreneurship and innovation within the business across developed nations (Turro et al., 2020), there is a clearly a gap in understanding the distinctive dynamics of the external environment's role in terms of formal and informal institutions on the development of intrapreneurial activity, specifically from emerging economies (Basingab et al., 2023). This article fills the available literature by investigating and responding to the call to empirically examine the effect of organization external environments on the development of intrapreneurial activity in the context of Saudi Arabia that considers evolved significantly, driven by Vision 2030 initiatives that promote economic diversification, and foster a culture of entrepreneurship and innovation (Aljarodi et al., 2024). The purpose of this research is to investigate whether the external environment, in terms of formal or informal institutions, affects the likelihood of employee Intrapreneurship and to what extent gender can benefit from each side of institutions in Saudi Arabia. The use of institutions theory (North, 1990; North, 2005) facilitates the study to understand the constraints that structure human interaction in terms of formal institutions (written constitutions) and informal institutions (unwritten constitutions). This framework can be applied to understanding the innovation of Intrapreneurship employees at an individual level and from each gender to be reflected on a national level of emerging economies (Turro et al., 2020). Nevertheless, this study application can assist researchers in understanding the effect of each side of institutions on each gender, organizations to promote intrapreneurship activity, and policymakers to invest in more friendly policies that create a favorable intrapreneurial environment for organizations within its nation. Also, it can add substantial value to comparative international entrepreneurship research, as it aligns with the discussions and insights presented by Terjesen et al. (2016). The paper presented is divided into six parts. The following part presents the literature review of institutions' direct and indirect effects on each gender intrapreneurship. The third section explains the methodology and sample used for the study, followed by the result. Section five discusses the topic and adds the implications of the findings. The last section summarizes the paper and presents the limitations and future research lines.

2. Literature Review

2.1. Context of Intrapreneurship

Studies indicate the phrase “Intrapreneur” refers to employees at any level of the organization who dedicated their time to improve a product or service without leaving their organization with “a bottom-up approach” (Badoiu et al., 2020; Bogatyreva et al., 2022; Turro et al., 2020). Intrapreneurial activity is driven by innovativeness (Turró et al., 2014), risk-taking (Caliendo et al., 2009), and proactiveness (Badoiu et al., 2020). The concept of Intrapreneurs is distinct from “corporate entrepreneurs” and from “entrepreneurs.” Urbano et al. (2022) showed that the activity initiated by a higher level of management and carried out by a lower level of employees in the organization hierarchy is called “corporate entrepreneurship.” Aljarodi et al. (2023) and Gonzalez-Serrano et al. (2018) defined an entrepreneur as someone who initiated a company to extend wealth and make a difference in their societies. Thus, intrapreneurs, corporate entrepreneurs, and entrepreneurs fall under the umbrella of entrepreneurship. They share an essential characteristic: the intrinsic passion and drive to ideate, establish, and manifest new things rather than a detached or passive approach. The consequences of intrapreneurial efforts on the organization's performance are shaped by its environment (Urbano et al., 2022; Zahra & Covin, 1995). Intrapreneurs capitalize on the company's existing resources to exploit future opportunities (Urbano et al., 2024). The intrapreneurial effort undertaken should help the company maintain its innovative edge, which can have a favorable influence on the government by reflecting on the economy in terms of employment and industry development. Despite the potential benefits, intrapreneurs often face substantial challenges in navigating, such as resource limitations, cultural barriers, regional factors, and uncertain market conditions, threatening the organization's innovativeness (Kuratko & Audretsch, 2013). Therefore, deeper insights and analysis are needed into the entrepreneurial process as it unfolds in different constrained

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environments. This relevancy of intrapreneurship activities is indeed within developing and emerging economies, especially with market changes (Urbano et al., 2024), which create a solution for companies to stay competitive within a fast-changing environment (Kraus et al., 2012). Compared to organizations in developed nations, firms in developing countries often lack intangible assets (Guillén & García-Canal, 2009). Thus, the research focuses on how the institutional context impacts and informs an employee's choice to become an intrapreneur within the tourism industry. The tourism industry is considered an untapped resource in Saudi Arabia, and the government provides it with priorities and investment (SCEDF Saudi Council of Economic and Development Affairs, 2016). Intrapreneurship in the context of the study is defined as employees developing new activities for their employer (Zahra & Covin, 1995). The rules within regulatory environments, beliefs and values within national culture, and organizational restrictions are the main factors that shape entrepreneurial behaviors (Stam, 2013; Urbano et al., 2024).

2.2. Hypotheses and proposed model

2.2.1. Institutions and Employee Intrapreneurship

Institutions explain the pivotal role of shaping productive activities ultimately connected to economic results (North, 1997). The concept of institutions is founded and connected to explain the economic growth "rules of the game," which explains the outcome of human interactions (North, 1990). The nation's set of institutions causes differences among each society (Urbano et al., 2024). According to North (2005), open societies establish incentives encouraging individuals to be more productive, while restrictive societies construct barriers that impede productive activities. These incentives and restrictions within societies are called formal and informal institutions. Based on North (1990), formal institutions can be examples of government laws and regulations, and informal institutions can be society's culture. Recent studies used institutions' theory as a lens to understand better environmental factors (Basingab et al., 2023; Bogatyreva et al., 2022; Turro et al., 2020). The theory claims that firm innovations positively reflect economic performance resulting from the entrepreneurial firm adapting its structure, process, regulations, and culture (Bruton et al., 2010; Scott, 1995). In other words, formal and informal institution systems create a favorable environment for firms, and, in turn, this system should reduce the uncertainty within human interactions. In addition, the intrapreneurial incentive results from intrapreneurs' interaction with societies and organizational rules and policies (Urbano et al., 2024). Thus, this study will use the institutional theory as a theoretical framework for two reasons: I) the framework can explain why organizations and individuals tend to conform to established norms, rules, and practices (Urbano et al., 2023), II) it helps to understand the institutional change that is currently happening in the context of Saudi Arabia as a part of the strategic plan called Vision 2030 (SCEDF, 2016). In this regard, we proposed that this theory can explain the institutional condition in terms of an external factor (formal institutions) and (informal institutions) at the country level; therefore, it affects employees' Intrapreneurship at the organizational level, as well as the moderating role of gender in this relationship (See Figure 1).

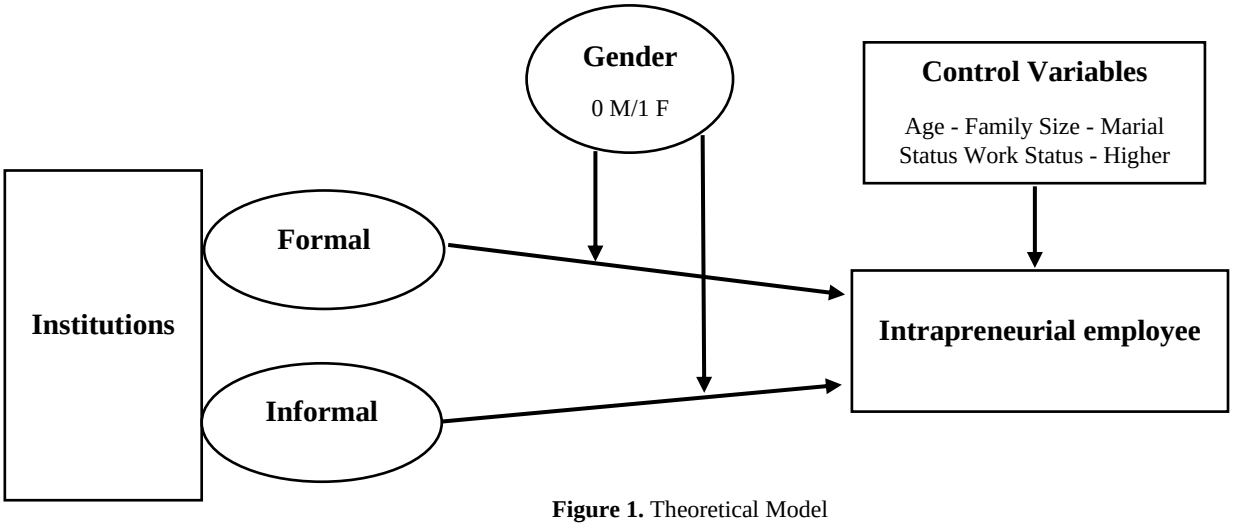


Figure 1. Theoretical Model
Source: Based on the authors' calculation

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2025 Volume 13 Number 2 (December)
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Prior studies show empirical evidence for the positive impact of institutions on entrepreneurial activity at the country level (Alvarez et al., 2011; Aljarodi et al., 2022; Basingab et al., 2023). Although some studies could not find the same effect (Van Stel et al., 2007), the government increases facilitation by requiring different institutions to reduce bureaucratic burdens; therefore, evidence supports entrepreneurial activity (Aljarodi et al., 2023). Rivera (2017) showed that businesses should adapt to formal institutional changes, such as economic and technological ones, so that intrapreneurs can find new opportunities to stay competitive and create innovative solutions for the company. Similarly, the aspiration of formal institutions through an educational system, a well-functional and fair court, and the ability of small firms to access resources should result positively in employee entrepreneurial activity in reaction to institutional flow (Lajqi & Krasniqi, 2017). A study of 184 firms in Turkey found a significant effect of management support on enhancing intrapreneurial behaviors, which explicitly reflects the positive support at the formal institutional level (Alpkan et al., 2010). Recent evidence from 29 developed and 31 developing countries showed that formal institutional factors such as economic freedom are significant predictors of Intrepreneurship at the organizational level and vary depending on the context of development (Urbano et al., 2023). In Latvia, Valka et al. (2020) anticipate from their findings that institutional support at the economic level affects intrapreneurial behavior directly or indirectly through risk-taking and a degree of trust in superiors and management. Falola et al. (2018) argued that employee intrapreneurial engagement can overcome economic hardship and influence organizational practices, which can be found in management practice policies and resource support. Based on these findings, this study proposes that formal institutions at the country level can enhance employee entrepreneurial activities by providing a better policy to support organizations and create economic stability. In this regard, we hypothesize that:

H1. *The formal institution factors have a positive impact on the likelihood of development of employee Intrapreneurship.*

The positive impact of informal institutions on employee tendencies to innovate and take a proactive role within their organization has been a subject of interest in various studies. Tseng and Tseng (2019) found six factors that increase entrepreneurial behavior within an established organization. These are motivating and educating employees, rewarding and assisting innovative-minded employees to reach their full potential, structuring the organization to accept newly minded ideas and encouraging employees to view an organization as a broad perspective. A Study on micro-enterprises from Turkey confirms the link between leadership style and increased innovation in employee behavior (Staub et al., 2019). An earlier study by Gapp and Fisher (2007) found that creating an innovative product results from having intrapreneurial teams who have already established or developed services within the organization. Other factors associated with employee attendance to be intrapreneurs include work discretion, mutual confidence, and the quality of the relationship between employees and top managers (Badoiu et al., 2020).

However, informal institutional factors encompass unwritten roles that are built inside the organization and can be extended outside of the organization. For example, Urbano et al., (2023) empirically found that fear of failure and media attention can predict intrapreneurial activities. Obschonka (2017) pointed out that intrapreneurial behavior can be similar to entrepreneurial activities by depending on culture, higher levels of individualism and lower levels of uncertainty avoidance. Thus, previous scholars have discovered several factors associated with informal institutions within/outside an organization that develop intrapreneurial behaviors, and this research proposed that informal institutions, such as societal influencer factors, should play an essential role in increasing intrapreneurial behaviors. Accordingly, we hypothesize that:

H2. *The informal institution factors have a positive impact on the likelihood of development of employee Intrapreneurship.*

The economic decisions made by individuals are determined by the institutions operating at the country level (Bogatyreva et al., 2022; Urbano et al., 2023). A country-level condition counts as one factor for disparities between men and women toward Intrapreneurship (Giménez & Calabrò, 2018; Pettersson et al., 2017). For example, the study of gender differences among 60 countries from 2014 to 2016 found that countries with active governments formulating and applying policies to support private businesses have advantages in increasing the likelihood of only male employees intrapreneurial behavior (Turro et al., 2020). Zhu and Zhu (2017) findings

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2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/w2448994246

indicate that firms in developed countries are inclined to participate in innovative endeavors due to several factors, including the presence of suitable regulatory systems, minimal government intervention, efficient regulation, and open markets. In Saudi Arabia, Alhammad et al. (2021) found that government interventions regarding procedures complications and ambiguity around some new policies affect many Saudi women to sustain their ventures. Another example of a formal institution is the Guardianship system, which restricts women's participation in employment activities, including signing new contracts or traveling, in certain Arab countries (Syed et al., 2018). However, recent studies have shown changes in countries like Saudi Arabia, where the guardianship system has been modified to grant women the freedom to engage with various government institutions and travel without a guardian (Aljarodi et al., 2023). Furthermore, policies that support women with children, such as maternity leave or the availability of daycare facilities, play a crucial role in motivating women to participate in the workforce rather than solely being homemakers (Al-Asfour et al., 2017; Syed et al., 2018). Despite this, women and men should benefit equally from the regulatory framework, resulting in flourishing employee attendance to Intrapreneurship (Amoroso & Link, 2018; Berglund et al., 2018).

This study assumes that these policies not only enable women to balance their familial responsibilities but also allow them to contribute their unique perspectives and ideas, fostering an environment conducive to innovation. We can conclude that the formal institutional view of intrapreneurship shows that gender differences exist because of government support and facilitation. Therefore, we present the following hypothesis:

H3. *Formal institutions increase the likelihood of employee Intrapreneurship for both men and women; however, the effect is stronger for men.*

The culture varies among different nations, which causes variation in entrepreneurial activity (Turró et al., 2014). The link of national culture to corporate entrepreneurship activities is noticed in earlier literature. Noting that corporate entrepreneurship is an organization's activities and behaviors that foster innovation, risk-taking, and the pursuit of new opportunities (Provasnek et al., 2017). In their earlier study, Morris et al. (1993) discovered that corporate entrepreneurship tends to be most prevalent in cultures with moderate individualism. Using the Hofstede's approach to define different cultures, power distance and uncertainty avoidance can cause differences among corporate entrepreneurship in different countries (Shane, 1995; Jan et al., 2024). Gender, informal institutions, and intrapreneurship are complex and context-dependent. For example, it found that in countries with lower economic freedom, there is a tendency for political and economic interests to exert control over the information accessible to the public (Bjørnskov, 2018); consequently, stories and information regarding entrepreneurs and intrapreneurs may be limited or unavailable (Urbano et al., 2023). Pia's information hinders employees from taking proactive initiatives (Eijdenberg et al., 2019). Dheer (2017) found that the successful entrepreneurship stories covered by media in developed nations are vital factors in increasing the number of individuals exhibiting intrapreneurial behavior. Alshebami (2021) showed that the presentation and coverage of individuals from both genders across various media channels should enhance psychological motivation. A recent study across developing and developed countries associated with employee intrapreneurship found that fear of failure is another informal institution associated with intrapreneurial behavior and has a higher impact on individuals within developed nations (Urbano et al., 2023).

Nonetheless, Langowitz and Minniti (2007) claimed that men and women have equally relevant perceptions influencing their decision to embark on entrepreneurship and start their businesses. Marlow (2020) argued that societal culture either fosters or discourages specific behaviors, including entrepreneurship, and these perceptions may vary based on the entrepreneur's gender. Aljarodi et al. (2023) found that informal institutions in Saudi Arabia such as stereotypes, can negatively influence the likelihood of females being involved in entrepreneurial activities, unlikely men. Several studies agreed upon the difficulties female entrepreneurs' presence could cause by male-dominated market (Giménez & Calabrò, 2018; Turro et al., 2020; Aljarodi et al., 2023). Thus, the study proposes that national culture impacts organizational cultures, which in turn can influence employee intrapreneurship, particularly when considering gender differences. Based on this understanding, we propose the following hypothesis:

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2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/w2448994246

H4. *Informal institutions increase the likelihood of employee Intrapreneurship for both men and women; however, the effect is stronger for men.*

3. Methodology

The study selected a sample comprised of workers from different government and private sectors who were involved in activities related to the tourism industry. The sample was chosen since the tourism sector reflects a rapidly changing environment, and the Saudi government invests heavily in providing individuals within the tourism industry with workshops and training sessions to become more innovative and create new opportunities (SCEDF, 2016).

3.1. Data collection and sample

The study began with the validation of the English version of the questionnaires. Then, it was translated into Arabic because it is spoken in Saudi Arabia. Next, a pilot test incorporated experts in the entrepreneurship area who are bilingual in both languages. After incorporating the respondents' feedback to enhance the survey's accuracy, the researchers distributed the final version of the questionnaire in July-September 2022. The study follows two techniques: selecting the sample group and others for collecting the data. First, the purposive sampling method was used (Campbell et al., 2020), and objects in the study were used according to the criteria of employees who may take innovative roles within their organizations. The study targeted the workshops advertised on different media channels for tourism workers seeking self-improvement. This assisted the researcher in delivering the survey to significant numbers of the selected target to service the study's objective. Second, the researchers used the "drop off and pick" technique to minimize bias and receive a higher response rate (Junod & Jacquet, 2023). The study targeted workshops at Umm Al Qura University in Saudi Arabia, which the researchers used to drop off the questionnaires and ask the participants to complete the survey voluntarily. As a result, the total number of surveys distributed was 600, and 550 surveys were collected. Out of which 550 surveys, 98 were rejected due to incompleteness. The final sample is 452 completed surveys, representing a 75% response rate. The study followed the rule suggested by the previous study for having at least ten times observations per predictor (Austin & Steyerberg, 2015). Based on this rule, the response rate is considered suitable, and the final sample size is sufficient for analysis.

3.2. Discerption of variables

Condition	Description	Minimum	Maximum
***Dep. Binary Variable*:** **Intrapreneurial employee**	Take value 1 when the respondent has been developing new activities for his/her employer in the past three years, 0 for no.	0	1
Independent variable			
Formal institutions	Government organizations in this country assist Individuals with starting their own business.	1	5
	The government sets aside government contracts for new and small businesses.	1	5
	Local and national governments have special support available for individuals who want to start a new business.	1	5
	The government sponsors organizations that help new businesses develop.	1	5
	Even after failing in an earlier business, the government assists entrepreneurs in starting again.	1	5
Informal institutions			
	Turning new ideas into businesses is an admired career path in this country	1	5
	In this country, innovative and creative thinking is viewed as the route to success.	1	5
	Entrepreneurs are admired in this country	1	5
	People in this country tend to greatly admire those who start their own business.	1	5
Control variables			
Age	The respondents were asked to identify their age?	18	67
Gender	Take value zero when the participants selected male gender, one for females	0	1

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
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Family Size	The respondents were asked to identify their family size?	0	16
Marital Status	The respondents were asked to identify their marital status. (harmonized into 1 for being single; and zero otherwise)	0	1
Work Status	The respondents were asked to identify their work status. (harmonized into 1 for having a full or part-time job only; zero otherwise)	0	1
Higher education	The respondents were asked to identify their education. (harmonized into 1 for those who attained secondary education and higher; zero otherwise)	0	1

Table 1. Description of variables.
Source: Based on the authors' calculation

The study established the survey questions based on benchmarking discussed earlier in the literature and operationalized them as follows. Table 1 reports the five statements used to measure the formal institutions and the four statements for informal institutions, which are computed later into latent variables. Also, it includes the description of control variables.

Regarding the dependents factor (Intrapreneurial employee), the paper is measured by binary variables, which takes value 1 when the respondent has been developing new activities for his/her employer in the past three years, 0 for no. This measurement was established earlier by the Global Entrepreneurship Monitor Report "GEM" and has been used by previous research (e.g., Stam, 2013; Turro et al., 2020). Likewise, regarding the independence factors, this research measured the formal institutions and informal institutions dimensions by using Likert scales (1 strongly disagree to 5 strongly agree) and based on earlier findings that assessed the country's institutional profile for entrepreneurial activity (Busenitz et al., 2000) and applied later by (e.g., Manolova et al., 2008; Urban, 2019).

The paper used several control variables because the earlier empirical findings show that individuals entrepreneurial activity might be affected by other factors, such as demographic characteristics (Braunerhjelm et al., 2018). First age: Dilli & Westerhuis, (2018) show that entrepreneurial activity usually starts in the middle of workers' careers. Second is gender, which empirical evidence reveals gender distributional differences between women and men involved in entrepreneurial activity, specifically in career choices (Guerrero and Marozau, 2022); hence, we control for gender to account for this effect. The third concerns family size. Youssef et al., (2021) demonstrated that family support increases the likelihood of young individuals for becoming entrepreneurs. Since Saudi Arabia is considered a collectivist society, and the young generation comprises 60% of the total population, with a common tradition of having a larger family and strong social ties (Aljarodi et al., 2024), the study controls for family size, as it may impact an individual's career choices. The Fourth relates to work status; the study control work status as the earlier findings prove it is relationship for the gender gap in entrepreneurial initiatives and indicating that a person with full or part time job have higher likelihood to involved in entrepreneurial activity (Dilli & Westerhuis, 2018). Lastly, Martiarena (2013) demonstrates that the high numbers of entrepreneurs within their organizations who have a high a level of education. Therefore, the study controls this factor to seek its effect.

3.3. Data quality checks and analysis

The research follows two analysis steps to check the reliability and validation of the data set before computing the final analysis. First, the reliability test (Cronbach's Alpha) and Composite Reliability are determined for internal consistency of the Likert scale variables. A score of 0.7 or higher presents a positive indication to proceed with factor analysis (Gliem & Gliem, 2003; Hair et al., 2010). Table 2 shows the indication numbers of the reliability test above 0.7, which is considered a clear indication that all the items consistently measure their corresponding construct. Next is a validation to strengthen the findings of the hypotheses. Average Variance Extracted AVE) was calculated, and the result shows that the constructs are equal and above 0.5, which considers the variations in the items can be explained by the latent variables (Fornell & Larcker, 1981). Thus, with all the clear indications above, the study proceeded with EFA Exploratory Factor Analysis (Hair et al., 2006) using STATA 14.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/w2448994246

Table 2. Loadings, Reliability and Convergent Analysis

Construct	Loadings	Factor Analysis	Reliability Analysis		Convergent Validity
		KMO	Cronbach's α	CR	AVE
Formal Institutions		.8712	.8789	.8730	.581
Item 1	.7702				
Item 2	.7334				
Item 3	.8380				
Item 4	.7826				
Item 5	.6771				
Informal Institutions		.7130	.7467	.843	.575
Item 1	.6914				
Item 2	.7725				
Item 3	.8253				
Item 4	.7362				

Notes: Source: Based on the authors' calculation
KMO: Kaiser-Meyer-Olkin ≥ 0.70
CR: Composite Reliability ≥ 0.70 (Hair et al., 2010).
AVE: Average Variance Extracted ≥ 0.5 (Fronell & Larcker,1981)

Next, the study conducted a Person correlation matrix to analyze the relationships among several independent and control variables to avoid multicollinearity. So, the variance inflation factor (VIF) has been calculated. The result indicates no concern about multicollinearity among the variables that might affect the significance of the main parameters in the regressions; the VIF values were lower than 4, as seen in Table 3 (Hair et al., 2010). Given the nature of the dependent variable, a binominal logistics regression was used with a binary dependent variable with two categories to predict the likelihood of individuals falling into employee intrapreneurial activity. This statistical technique serves the study's objective about the cause and effect of the relationship between independent and dependent variables (Crawford, 2006; Austin & Steyerberg, 2015).

4. Findings

4.1. Descriptive statistics and correlation analysis

Table 3 reports the descriptive analysis and correlation matrix of the applied variables. As a result, 76% of the respondents were categorized as Intrapreneurial employees. Regarding age, the average age of respondents was 35 years old. The gender distributions were 65 % men and 35% women. In terms of family size, the average respondent has two siblings. Further, regarding marital status, 40% of the respondents are single, while the rest are married and widowed. Finally, 76% of the respondents had a full-time or a part-time job, while 87% had a bachelor's degree or higher. Also, the results show that the median value of the newly constructed variables is larger than 3.

Then, the study ran a correlation test to determine the relationship between dependents, independents, and control variables. As noted earlier, the variables used are not highly correlated, and there is no concern of multicollinearity, as the VIF is below 4 (see Table 3). Therefore, based on the guidelines provided by (Cohen, 1988), the correlation coefficients between all factors indicate small at ($0.1 < r < 0.3$) to high correlation at ($r > 0.5$). Table 3 shows that there is a positive correlation between Intrapreneurial employee and formal institutions (.0937), and Intrapreneurial employee and control variables such as age at (.2484), family Size (.1862), work Status (.2734) indicates that there is a small positive relationship between these variables. In contrast, the correlation between Intrapreneurial employee and marital status at (-.1772) indicates a small negative relationship. A moderate correlation was reported between informal and formal institutions (.3512). The strong correlation was among control variables such as family size and age at (.6705) and marital status with age at (-.6601). Thus, these significant results at ($p < 0.10$; $p < 0.01$; $p < 0.001$) build a strange base for the upcoming regression models for finding the relationship between the variables and explaining the cause and effect.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/w2448994246

Variables	Mean	SD	1	2	3	4	5	6	7	8	VIF
Intrapreneurial employee	.76	.43	1								
Formal Institutions	3.51	.79	.0937**	1							1.20
Informal Institutions	3.12	.53	.0319	.3512***	1						1.20
Age	35.03	10.32	.2484****	-.1008**	-.0902**	1					2.5
Gender	.65	0.48	-.0686	.0570	.2165***	-.2934***	1				1.25
Family Size	1.69	2.15	.1862***	-.1181**	-.0918*	.6705***	-.2792***	1			2.14
Marital Status	.40	.49	-.1772***	.0688	.0693	-.6601***	.2771***	-.6258***	1		2.05
Work Status	.76	.42	-.2734***	-.1484***	-.0608	.4632***	-.3115***	.2341***	-.3733***	1	1.45
Higher education	.87	.34	-.0076	-.1864***	-.0733	.0664	.0653	.0407	-.0826*	.1678***	1.08

Table 3. Descriptive statistics and Correlation matrix

Notes: Source: Based on the authors' calculation
∗ All correlations are significant at the ***Significant at p # 0.01; **significant at p # 0.05, * significant at p # 0.10

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4.2. Regression analysis

The hypotheses testing for this research was conducted using binomial regression. The first model explains the direct relationship between the dependent variables (Intrapreneurial employee and independent variables (Formal Institutions and Informal Institutions) along with the control variables (Age, Gender, Family Size, Marital Status, Work Status, and Higher education). The second model adds the same variables as the first model and the interaction effect of gender on the relationship between Intrapreneurial employee and formal institutions. The third model is repeated from the second model but adds the interaction of gender and informal institutions. The model coefficient of R-squared ranges between 0.1099 to 0.1326 (see table 4). According to Hair et al. (2011), there is no general rule for the R-squared value, and it depends on the research area. Also, Several similar studies reported lower R-squared (i.e., Aljarodi et al., 2022; Hacioglu et al., 2012). Therefore, the study considered the reported R-squared adequate.

Model 1 justifies the earlier assumption about the effect of external factors in terms of formal and informal institutions on employees' likelihood of becoming intrapreneurial. Hypothesis 1 proposed that the formal institutional factors positively impact the likelihood of employee Intrapreneurship development. The marginal effect was positive and significant (β= .49; $p < 0.001$). This means that a unit increase in formal institutions will result in a corresponding increase of 0.49 units in the likelihood of employee entrepreneurial behavior. Thus, hypothesis 1 is strongly supported. Hypothesis 2 proposed that the informal institutional factors positively impact the likelihood of employee Intrapreneurship development. The result shows a marginal effect is not in line with a prior expectation with a negative sign and non-significant (β = -.01; $p > 0.10$). Thus, hypothesis 2 is rejected. Regarding the control variables, work status was the only factor from the control variables in the model that showed a positive and significant sign (β = 1.27; $p < 0.001$), which was expected as being an employee in a full-time job or part-time increases the likelihood to be an intrapreneurial employee.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/w2448994246

Table 4. Logit results explaining intrapreneurial employee

VARIABLES	Model 1		Model 2		Model 3	
	Coef.	SE	Coef.	SE	Coef.	SE
Independent variables						
H1: Formal Institutions	.49***	.17	-.37	.31	.48***	.17
H2: Informal Institutions	-.01	.24	-.09	.24	-.38	.43
Control variables						
Age	.03	.02	.03	.02	.03	.02
Gender	-.32	.27	-4.55***	1.34	-2.01	1.68
Family Size	.15	.09	.18*	.09	.16*	.09
Marital Status	.19	.34	.17	.34	0.13	.34
Work Status	1.27***	.31	1.29***	.32	1.27***	.31
Higher education	-.27	.37	-.29	.37	-.23	.37
Moderation						
H3: Formal Inst. # Gender			1.19***	.36		
H4: Informal Inst.# Gender					.53	.52
Observations	451		451		451	
Log-likelihood	-221.99		-216.34		-221.48	
***R*-squared**	0.1099		0.1326		.1120	
Wald *x2*	54.83		66.14		55.87	

Notes: Source: Based on the author's calculation. The reported coefficients are marginal effects. ***Significant at p # 0.01; **significant at p # 0.05, * significant at p # 0.10.

Model 2 was computed to determine if gender matters in the relationship between formal institutions and employee entrepreneurial behavior. Hypothesis 3 proposed that formal institutions increase the likelihood of employee Intrapreneurship for both men and women; however, the effect is stronger for men. The marginal effect reports a positive and significant sign ($\beta = 1.19$, $p < 0.001$). Figure 2 demonstrates that the effect of formal institutions on male workers is higher than that of women in developing entrepreneurial behavior. Thus, hypothesis 3 is strongly supported. The remaining control variables presented a consistent result to the prior model except for the family size, which became positive and significant ($\beta = 0.18$, $p < 0.1$).

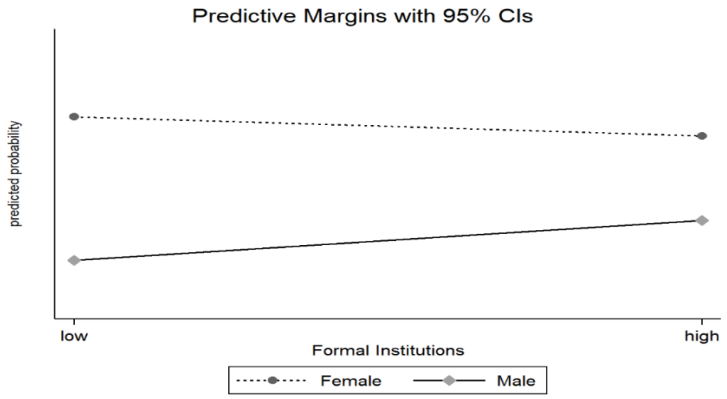


Figure 2. Linear Prediction of Intrapreneurial employees (Formal Institutions)
Source: Based on the author's calculation

Similar to model 2, model 3 determined the proposed hypothesis 4, which is informal institutions increase the likelihood of employee Intrapreneurship for both men and women; however, the effect is stronger for men. The marginal effect is non-significant ($\beta = 0.53$; $p > 0.10$). Therefore, hypothesis 4 is not supported. At the same time, control variables remain consistent with model 2. Table 5 below summarizes the result.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/w2448994246

5. Discussion and implications

This study empirically measured employee attendance for innovation within their firms and how it can be differentiated among genders by being linked to the country's institutional environment. To achieve this objective, the study uses different factors that measure formal and informal institutions developed by earlier studies and integrated and contextualized to measure the behavior of employee intrapreneurial activities in Saudi Arabia. The article extends current views of the institutional environment by explaining its relationship to employee entrepreneurship activity among genders in an emerging market context, Saudi Arabia. Overall, the empirical results show the positive effect of formal institutions on Intrapreneurial employee, while informal institutions are negatively not associated with Intrapreneurial employee. We further find that the effect of formal institutions on Intrapreneurial employee is moderated by gender.

The research contributes to the intrapreneurship literature. First, the study extends institutional theory in entrepreneurial research by emphasizing the importance of formal institutions in Intrapreneurial employees. The first main findings show a significant positive relationship between formal institutions and employee entrepreneurial activity, suggesting that supportive formal institutions, such as government policies to support local businesses and government providing special projects to new and small businesses, can favor fostering entrepreneurial behavior within employees. the results are consistent with previous studies highlighting that formal institutions likely provide a conducive environment that encourages and supports innovation (Rivera, 2017), accessible to different resources (Lajqi & Krasniqi, 2017), and risk-taking (Valka et al., 2020). The positive relationship between formal institutions and employee entrepreneurial activity implies that organizations operating in environments with supportive formal institutions experience higher levels of intrapreneurship. However, this empirical evidence can underscore the importance of considering the external environment and formal institutions to increase innovation and improve organizational performance.

In contrast, the second findings show no evidence of societal support for employee entrepreneurial activity. The contrary results of the previous findings (Obschonka, 2017; Urbano et al., 2023) can be explained through Hofsted (2003). Saudi Arabia is under highly collectivist societies, power distance and uncertainty avoidance. These established values were evidence to cause individual behavior anxiety about risk-taking or change (Morris et al., 1993; Shane, 1995; Venaik & Brewer, 2010; Brewer & Venaik, 2011). This implies that the external environment presented by informal institutions limits employee creativity and opportunities to explore new ideas; therefore, employees have not prioritized these factors yet.

Third, this study extends the literature on intrapreneurship by investigating the role of gender as an interaction between each side of institutions and employee intrapreneurship. Note that the study investigates the influence of formal institutions with questions that refer to governmental and societal support of entrepreneurial activity (Busenitz et al., 2000; Laužikas et al., 2025). As the institutions existed to be connected to individuals by guiding both behaviors and restrictions (North, 1990), gender within this study represents a contextual institutional factor that influences the relationships between institutions and employee Intrapreneurial, particularly formal institutions. The formal institution's initiatives are more likely to encourage male employees to take an innovative step within their organization than female. Scholars have recently pointed out the value of gender (Alhammad et al., 2021; Turro et al., 2020) and how it is contextual from one nation to another (Mustafa et al., 2018). Gender differences are a necessary condition factor for future research to consider within emerging markets that work to foster the participation of females.

The findings of the research have managerial implications. First, the study shows that employee influence by formal institutions increases their likelihood of having a proactive innovative role. Organizations should be aware of the impact of formal institutions on employee entrepreneurial activity and strategically align their internal practices and structures to leverage these external influences. They can create an organizational culture that values and rewards entrepreneurial behavior, establish mechanisms for idea generation and implementation, and provide resources and support to employees pursuing entrepreneurial initiatives. Second, this study highlights that business owners should build a system to encourage their employees' entrepreneurial spirit. Organizational owners may work towards breaking down silos, promoting open communication channels, and

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
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empowering employees to take ownership of their ideas and projects. Encouraging a culture that embraces experimentation, tolerates failure as a learning opportunity, and rewards entrepreneurial efforts can help mitigate the negative influence of informal institutional factors on Intrapreneurial employee. Gender should also be considered when creating an intrapreneurship system within an organization since both formal and informal factors within the institutional environment represent an equal opportunity for encouraging both genders to increase their entrepreneurial behavior and for business owners to adapt it to gain competitive advantage.

Conclusion

This research provides empirically a deeper understanding of the relationship between the external environment of the organizations represented by formal and informal institutions on each gender to become an intrapreneur by using primary data collated in 2024 from Saudi Arabia. The findings of this paper succeeded in proving hypothesis 1 states that the formal institution factors have a positive impact on the likelihood of development of employee Intrapreneurship. The influence of formal institutions on individuals to become an intrapreneur is positive. Therefore, the increasing government support for organizations significantly and positively encourages employees to become intrapreneurs. The results also succeeded in proving hypothesis 3, which states that formal institutions increase the likelihood of employee Intrapreneurship for both men and women; however, the effect is stronger for men. The influence of formal institutions appears to be significant and positive on males more than females in developing entrepreneurial behavior. Consequently, the traditional gender roles and the supportive legal system that existed before the recent reform policies, which have empowered females over the last ten years, still seem to be reasons affecting females in developing entrepreneurial behavior. The results show no statistical support for hypothesis 2, which states that the informal institution factors have a positive impact on the likelihood of development of employee Intrapreneurship, and hypothesis 4, which states that informal institutions increase the likelihood of employee Intrapreneurship for both men and women; however, the effect is stronger for men. Therefore, the research findings conclude that the influence of informal institutions on the development of employee Intrapreneurship does not differ significantly between males and females.

The contribution of this study to the existing literature is the development of a deeper understanding of the institutional factors that impact the growth of employee intrapreneurship activity between genders and in the context of Saudi Arabia. The findings of this research integrate intrapreneurial behaviors, allowing us to view intrapreneurship as a process influenced by external organizational factors that both formal and informal institutions shape. It provides theoretical and managerial foundations for future research in the field, offering valuable insights and recommendations for policymakers to continue developing policies and for businesses to cultivate an intrapreneurial culture that encourages employee creativity, innovation, and entrepreneurial behavior.

While the study attempts to provide several significant outcomes, it notices several challenges that should alert future studies. First, while the study empirically finds the effect of institutions on each gender to be intrapreneurial employees, the question arose of whether individual backgrounds or geographical area predict their intrapreneurial behavior. Future research can empirically examine this question. Even though, the previous studies discuss the organizational effect of predicting intrapreneurial behaviors, researchers have not yet provided empirical evidence on linking the different individual backgrounds and geographical areas within a single context and related to individual intrapreneurial behavior, which can be an interesting area to discover by future studies. Second, the study data was collected from individuals in their first development stage to take more active roles within their organizations. This result is not generalizable to different industries and employees exposed to different development programs. Future studies could compare this result with samples at different stages of employee development, which should provide a bigger picture of employee intrapreneurial activity. Third, this study focuses on Saudi Arabia, and findings cannot be universal to other countries. Therefore, future studies can replicate the current study and see if the results are similar or different, which would open new areas. Finally, it should be noted that the findings did not consider the size of the organization where that employee works. This factor limited the study from understanding if the organization size would affect employee intrapreneurial behavior. Future research should consider this factor to seek institutions' influence on each gender working in small, medium, or large organizations.

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UNDERSTANDING ACADEMIC SATISFACTION AMONG GENERATION Z: THE ROLE OF MENTAL WELLBEING AND INSTITUTIONAL EQUITY*

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Abstract. The study focuses on the analysis of factors influencing the satisfaction of Generation Z students with the university environment, particularly in the areas of interpersonal relationships, mental well-being, and the perception of inclusiveness. The aim of the research was to examine how Generation Z students perceive the quality of interpersonal relationships and inclusive conditions at the university, and how these dimensions affect their satisfaction with the academic and support environment. The research sample consisted of 277 respondents from Alexander Dubček University of Trenčín. Based on data from a questionnaire survey and subsequent multiple linear regression analysis, two models were tested. In the first model, a statistically significant impact of the perceived quality of relationships with teachers and the university's care for mental health on students' satisfaction with the accessibility of instructors was demonstrated. In the second model, satisfaction with the support system for students with specific needs was significantly influenced by the perception of equal opportunities, while the subjective importance of inclusion proved to be a less convincing predictor. However, the combination of both variables increases the explanatory power of the model. The findings point to the need to systematically strengthen the interpersonal competencies of teachers, develop programs to support mental well-being, and translate inclusive values into visible measures. Universities that actively support relationships, equality, and mental well-being create more favorable conditions for the academic development of students.

Keywords: Generation Z; mental health; interpersonal relationships; inclusion; university environment

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1. Introduction

University studies represent a significant developmental phase for young people, which is associated not only with academic demands but also with personal and social development. Generation Z students in particular face specific challenges related to the environment in which they grew up. Digitalization and constant connectivity through technology influence their ability to concentrate, build relationships, and effectively cope with stress (Dwidienawati et al., 2025; Mabungela et al., 2025). Research by Dwidienawati et al. (2025) points out that the well-being of students of this generation is influenced by a combination of internal factors, such as extraversion or resilience, and external factors, such as social support or technological habits. Their findings confirm that social support has a strong positive impact on mental well-being – both directly and indirectly through the strengthening of resilience. In contrast, the impact of technological factors, such as FOMO or excessive screen time, was not statistically confirmed in their research, which indicates the need for further investigation.

In relation to reducing students' psychological burden, mindfulness has proven to be an effective strategy – a technique focused on conscious and non-judgmental awareness of the present moment. Alvarado-García et al. (2025) demonstrated in their study that a systematic twelve-week mindfulness program led to a reduction in stress, anxiety, and depression among university students, while also improving sleep quality, perception of social support, and overall life satisfaction. These results support the need to incorporate psychological interventions into the regular university environment as part of preventive and developmental programs for students.

An important element that shapes not only the academic experience but also the overall well-being of students is the quality of interpersonal interactions. The study by Wong and Chapman (2023) analyzed various forms of interactions – formal and informal relationships among students and interactions with the instructors themselves – and found that each of these forms of interaction significantly influences different aspects of study satisfaction. Their research shows that quality relationships in the academic environment can significantly contribute to a better university experience and higher overall student satisfaction with their studies.

From the above, it follows that students' mental well-being and academic satisfaction are the result of the interplay of multiple factors – personality traits, the quality of the social environment, and specific supportive approaches. The purpose of this study is to build on existing knowledge and examine how mindfulness, social support, and the quality of interactions influence the subjective well-being and satisfaction of students in the university environment. The focus is to identify key variables that contribute to creating a positive academic experience for Generation Z students, and thereby support the development of effective intervention approaches in the field of higher education.

2. Literature review

Research on the satisfaction of Generation Z students with the academic environment is gaining increasing importance in the context of the growing emphasis on mental health, inclusion, and the quality of relationships within higher education. The starting point is the fact that a significant portion of students enter university already showing symptoms of mental disorders, while only a small fraction of them use the available mental health services (Osborn et al., 2022). This indicates a significant mismatch between needs and the availability of support, which is especially crucial for Generation Z students, who have been profoundly affected by events such as the COVID-19 pandemic (Shaikh et al., 2023).

The mental health of Generation Z students is also closely related to the use of digital technologies. Research has shown that technology dependency is a significant predictor of depression, anxiety, stress, and sleep disorders (Surat et al., 2021). Similar findings were also presented in a study focused on smartphone addiction among Generation Z university students, which demonstrated that excessive use of mobile devices negatively affects their mental health and the quality of their social life (Ozkan & Solmaz, 2015). High demands for constant connectivity may contribute to weakened student well-being, which also affects their assessment of the availability and quality of relationships with teachers.

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Positive perception of relationships with teachers has repeatedly proven to be a strong predictor of academic engagement, satisfaction, and performance. A systematic review (Prananto et al., 2025) confirms that perceived support from instructors is closely linked to students' motivation and persistence. The meta-analytic approach by Göktaş and Kayu (2023) distinguishes between intrapersonal and interpersonal aspects of pedagogical relationships, with the interpersonal dimension (a positive student–instructor relationship) having a moderately strong positive effect on academic performance. These findings are also supported by the research of Liu (2024), which demonstrated that a positive relationship between student and teacher directly increases academic engagement, with this effect being partially mediated by perceived social support and the level of academic pressure.

In a similar vein, Di Lisio et al. (2025) emphasize the importance of the dimensions of a 'safe haven' and a 'secure base' within attachment theory. These dimensions support not only academic outcomes but also the prevention of early dropout. Quality interpersonal bonds can thus serve as a protective factor against failure and demotivation. These findings are also confirmed by a systematic review of 37 longitudinal studies, which demonstrated that the quality of the teacher–student relationship is strongly linked to academic (dis)engagement, (under)achievement, and early school leaving, with a particularly strong protective effect for vulnerable groups of students - e.g., socially disadvantaged, those with special needs, or with mental health issues (Di Lisio et al., 2025).

Inclusive education and equal opportunities appear as other key aspects of student satisfaction. In the European context, these topics are increasingly perceived as a standard of academic quality (Siri et al., 2022). However, approaches to diversity, as well as support for students with various needs, remain insufficiently addressed at a systemic level, as illustrated by students' own statements about the need for personalized and targeted support (Hitches et al., 2024). Slovak research (Sirotová & Michvocíková, 2023) pointed to specific categories of needs identified by students in the areas of personal growth and educational support, which often remain unmet.

The complex interconnection between equality, quality, and the availability of inclusion in the university environment was elaborated by an international team within the B-CAUSE project (Khoo et al., 2024), where it was shown that an inclusive academic environment must be conceived as a whole-institutional process with an emphasis on participation, openness, and plurality. Factors such as teaching style, availability of support, and organizational flexibility have direct implications for the satisfaction of especially marginalized groups of students (Li et al., 2024).

At the same time, it appears that the social support students perceive in the university environment influences their motivation and academic engagement. This mechanism was also demonstrated through a chain mediation model (Chen et al., 2023), which highlights the importance of life satisfaction as a mediating factor between social support and engagement. Similarly, Xin (2022) identified that the satisfaction of basic psychological needs (autonomy, competence, and relatedness) mediated the relationship between social support and engagement, with this effect being more pronounced among students with a higher level of gratitude.

Similarly, feelings of belonging and satisfaction with the university have been shown to be predictors of academic success, especially among students in science-related fields (Kenney & O'Halloran, 2024), where adaptation problems tend to be the most pronounced. Increasing student satisfaction is also a significant pillar for the sustainable development of university campuses (Pedro et al., 2023), which highlights the connection between the ecological and social dimensions of the university environment.

Barriers to accessing mental health care among racially marginalized students have been identified as multilayered and culturally conditioned (Hardy et al., 2025), with evidence showing that systemic discrimination and cultural incompetence play a significant role in the underutilization of support. These findings confirm the need for culturally sensitive interventions and adapted support models.

The importance of inclusive education has been further confirmed by studies that emphasize the need for systematic teacher training and the removal of barriers in the implementation of inclusive measures (Jardinez

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2025 Volume 13 Number 2 (December)
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& Natividad, 2024; Lister et al., 2022). The 'Universal Design for Learning' approach appears to be a practical framework for creating an environment accessible to all.

Gender equality of opportunity remains a challenge, as shown by research in Spain, where many future teachers lack sufficient knowledge of the basic concepts of gender equality (Merma-Molina et al., 2025). Educational innovations in this area can significantly contribute to reducing stereotypes and prejudices already within teacher training.

Equally important is the continuity of support for students from marginalized backgrounds throughout their entire studies – as shown by a 2021 study (Matabane & Matabane, 2021), systematic support leads to better academic outcomes and higher retention. The importance of non-pedagogical factors for student satisfaction is also confirmed by research from Slovenia, which shows that not only the quality of teaching, but also administrative support and the physical environment influence satisfaction with studies (Jereb et al., 2018).

From the perspective of Generation Z psychology, it is important to pay attention to their future expectations and anxieties. Students express uncertainty, concerns about employability, and a tendency to migrate abroad (Dikec et al., 2023), which may influence their motivation and perception of the university environment.

3. Methodology

The main objective is to examine how Generation Z students perceive the quality of interpersonal relationships and inclusive conditions at the university, and how these dimensions affect their satisfaction with the academic and support environment.

Two research questions emerged from this objective:

- **Research Question 1:** What factors influence students' satisfaction with the availability of teachers and interpersonal relationships at the university?
- **Research Question 2:** What factors influence the perception of university support for students with specific needs and minorities?

To answer them, two analytical models were formulated consisting of the following variables and hypotheses:

Model 1 – Satisfaction with the Availability of Teachers

- **Dependent variable (Y):** Satisfaction with the availability of teachers outside of teaching
- **Independent variables:**
  - **X1:** Perception of the quality of relationships with teachers
  - **X2:** Perception of the university's care for mental health

Formulated hypotheses:

- **H1:** Perception of the quality of relationships with teachers positively influences satisfaction with their availability outside of teaching.
- **H2:** Perception of the university's care for mental health positively influences satisfaction with the availability of teachers.
- **H3:** The combination of perceived interpersonal relationships and mental well-being is a significant predictor of satisfaction with teacher availability.

Model 2 – Perception of University Support for Disadvantaged Students

- **Dependent variable (Y):** Perception of support for students with specific needs
- **Independent variables:**
  - **X1:** Subjective importance of an inclusive environment
  - **X2:** Perception of equality of opportunity

Formulated hypotheses:

- **H4:** The importance of inclusion positively influences the evaluation of university support for students with specific needs.

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- **H5:** Perception of equality of opportunity positively influences the evaluation of university support for disadvantaged groups.
- **H6:** The combination of perception of inclusion and equality of opportunity is a significant predictor of the perception of university support.

The empirical part of the research was focused on identifying the attitudes of Generation Z students towards selected aspects of the academic environment – specifically on the perception of interpersonal relationships, availability of pedagogical support, mental well-being, inclusion, and equality of opportunity. Data collection took place in December 2024 in the territory of the Slovak Republic, specifically at Alexander Dubček University of Trenčín in Trenčín.

The target group consisted of students from various faculties and study programs belonging to Generation Z. A total of 277 respondents participated in the survey, with the sample being representative in terms of the structure of the university's student population. Data collection was conducted voluntarily and anonymously and was carried out in cooperation with the university, which increased the credibility of the responses.

The questionnaire was created using the Microsoft Forms tool. The questions were formulated in the form of statements, which respondents evaluated on a five-point Likert scale, where 1 represented the statement 'strongly disagree' and 5 'strongly agree.' This form of scale made it possible to capture the degree of agreement or disagreement with individual statements and at the same time ensured the quantifiability of responses for the purposes of statistical processing.

Two statistical methods were used to test the hypotheses:

- Correlation analysis, which made it possible to identify the direction and strength of relationships between individual variables.
- Multiple linear regression analysis, through which the predictors of the dependent variables in both models were tested. Statistical testing was conducted at a significance level of $\alpha = 0.05$.

Linear regression modeling (LRM) was applied as a suitable tool for the analysis of responses obtained through the Likert scale. The assumptions for the use of linear regression were met – the assumption of normality was verified, linearity was ensured by the positive orientation of the statements, autocorrelation is excluded due to one-time data collection, and multicollinearity was not detected.

The chosen methodological approach made it possible to reveal which psychological and social factors within the academic environment are decisive for the satisfaction of Generation Z students with relationships at the university and with the support system intended for disadvantaged groups.

4. Findings

This section presents the results of the quantitative analysis, the aim of which was to verify the assumed relationships between selected psychological, social, and value variables in the context of higher education. The analysis was carried out using two regression models, each corresponding to one of the research questions. Model 1 focused on identifying predictors of students' satisfaction with the availability of teachers, specifically the influence of interpersonal relationships and care for mental health. Model 2 was oriented towards examining the influence of perceived inclusiveness and equality of opportunity on the evaluation of support provided to students with specific needs. The following text gradually presents the results of descriptive statistics, correlation relationships, and multiple linear regression analysis for each model separately.

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2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/m7682285735

Table 1. Descriptive statistics of the observed variables (model 1)

X1	*X1*	*X2*	*Y*
Mean	3,98916968	3,27436823	3,88086643
Standard Error	0,08596414	0,09114714	0,08063317
Standard Deviation	1,43072839	1,51699075	1,34200341
Kurtosis	-0,2758946	-1,2275888	-0,4944717
Skewness	-1,0575273	-0,234711	-0,7955876

Source: own elaboration

In the sample of 277 respondents, the highest average level of agreement was recorded for the variable 'Perception of the quality of relationships with teachers' (X1), where the mean value reached 3.99. This result suggests that students predominantly perceive interpersonal relationships with teachers positively. This is followed by 'Satisfaction with the availability of teachers' (Y) with an average of 3.88, indicating a relatively high level of satisfaction with the possibility of communicating with teachers outside of teaching. The lowest average value was recorded for the variable 'Perception of care for mental health' (X2), which reached 3.27, indicating some diversity of opinions in this area.

The variance of responses was highest for variable X2 (SD = 1.52), which indicates differing perceptions of the university's level of care for mental health. In contrast, the most consistent responses appeared for the dependent variable Y (SD = 1.34), which reflects a relative agreement among respondents in evaluating the availability of teachers.

All three variables showed skewness and kurtosis values within the acceptable range (±2), which supports the assumption of approximately normal data distribution.

Table 2. Correlation analysis (model 1)

	X1	*X2*	*Y*
X1	1		
X2	0,52889278	1	
Y	0,47297152	0,36494123	1

Source: own elaboration

Based on the correlation analysis between the variables, it can be stated that all observed relationships are positive, which means that higher values of one variable are associated with higher values of the other. The strongest relationship appeared between "Perception of the quality of relationships with teachers" (X1) and "Perception of care for mental health" (X2), where the value of Pearson's correlation coefficient reached r = 0.529, representing a moderately strong positive correlation. This result suggests that students who positively evaluate the quality of interpersonal relationships with teachers also more frequently perceive that the university cares about their mental well-being.

A similar, slightly weaker relationship was found between X1 and the dependent variable Y, where the coefficient reached r = 0.473. This indicates that students who perceive high-quality relationships with teachers are also more satisfied with their availability outside of teaching. The weakest, yet still positive and significant correlation was found between X2 and Y, with a value of r = 0.365, which can be interpreted as a mildly strong positive relationship. This implies that if students perceive the university as an entity that cares about their mental health, their satisfaction with pedagogical support increases accordingly.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
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Overall, it was shown that all variables are logically and statistically related, which creates a solid basis for testing causal relationships within the regression model.

Table 3. Regression analysis (model 1)

Regression Statistics					
Multiple R	0,49193106				
R Square	0,24199617				
Adjusted R Square	0,2364633				
Standard Error	1,17265046				
Observations	277				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	120,2886963	60,1443481	43,7378734	3,27327E-17
Residual	274	376,7798958	1,37510911		
Total	276	497,0685921			
	Coefficients	***Standard Error***	***t Stat***	***P-value***	
Intercept	1,96486039	0,21663665	9,06984294	2,3728E-17	
X1	0,36457808	0,058131087	6,27165424	1,3861E-09	
X2	0,14098665	0,054825514	2,57155185	0,01065211	

Source: own elaboration

Based on the results of the multiple linear regression, it can be stated that both independent variables – "Perception of the quality of relationships with teachers" (X1) and "Perception of care for mental health" (X2) – have a statistically significant impact on the dependent variable "Satisfaction with the availability of teachers" (Y). The value of the coefficient of determination $R^2 = 0.242$ indicates that the model explains approximately 24.2% of the variability in the dependent variable. In the social sciences, this represents an adequate explanatory power, with practical implications for the university environment.

The ANOVA test confirmed that the model is statistically significant as a whole ($p < 0.001$), which means that the variables X1 and X2 jointly explain changes in students' satisfaction with pedagogical support.

From the perspective of individual effects, the factor "Perception of the quality of relationships with teachers" had the greatest impact ($B = 0.3646$; $p < 0.001$), which suggests that the better students evaluate interpersonal relationships at the university, the higher satisfaction they express with the availability of teachers. "Perception of care for mental health" also had a positive and statistically significant impact ($B = 0.1410$; $p \approx 0.011$), although its intensity was weaker.

The resulting regression equation is as follows:

$$Y = 1{,}9649 + 0{,}3646\ X1 + 0{,}1410\ X2$$

This model shows that social interaction and support for mental well-being are key determinants of students' satisfaction with the accessibility of their teachers – the more positively these factors are perceived, the higher the satisfaction reported by respondents.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/m7682285735

Table 4. Descriptive statistics of the observed variables (model 2)

X1	*X1*	*X2*	*Y*
Mean	4,53068592	4,28519856	3,64259928
Standard Error	0,05591067	0,07503721	0,06953152
Standard Deviation	0,93053898	1,24886806	1,15723516
Kurtosis	2,34725729	1,17563057	-0,6310011
Skewness	-1,7885604	-1,5433876	-0,1743799

Source: own elaboration

In the sample of 277 respondents, the highest average level of agreement was recorded for the variable "Subjective importance of an inclusive environment" (X1), with a mean value of 4.53, which indicates a high level of importance that students attribute to inclusion in the academic environment. This is followed by the variable "Perception of equal opportunities" (X2), where the mean reached 4.29, confirming a positive perception of the university's approaches toward different groups of students. The lowest mean value was observed for the dependent variable – "Perception of support for students with specific needs" (Y), where the mean reached 3.64, which may indicate a certain caution or reservation on the part of respondents when evaluating specific support.

In terms of response variability, the greatest dispersion was recorded for the variable X2 (SD = 1.25), while the most compact responses were for X1 (SD = 0.93). The variable Y lies between them with a value of SD = 1.16, indicating moderate agreement in the perception of this area.

The skewness and kurtosis values of all three variables fall within the acceptable range from −2 to +2, confirming the approximate normality of the data.

Table 5. Correlation analysis (model 2)

	X1	*X2*	*Y*
X1	1		
X2	0,14677011	1	
Y	0,14648807	0,22872445	1

Source: own elaboration

Based on the correlation analysis between the observed variables, it can be stated that all identified relationships are direct and positive. This means that higher values of one variable are associated with higher values of the other.

The strongest correlation occurred between the variables "Perception of equal opportunities" (X2) and "Perception of support for students with specific needs" (Y), where Pearson's correlation coefficient reached a value of r = 0.229. This relationship represents a weak to moderate positive correlation, which suggests that the more positively respondents evaluate equal treatment of students from different backgrounds, the more often they believe that the university provides adequate support for students with specific needs.

Furthermore, a weak positive correlation was found between the variables "Subjective importance of an inclusive environment" (X1) and "Perception of equal opportunities" (X2), with a value of r = 0.147. The result suggests that respondents who consider inclusion an important part of the university environment also slightly more often evaluate the university as equal and fair toward different student groups.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
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The third observed relationship – between X1 and Y – also shows a weak positive correlation (r = 0.146), which points to a connection between how strongly students emphasize the importance of an inclusive approach and how they perceive the level of support provided by the university for students with specific needs.

Overall, it appears that despite the moderate intensity of all correlations, the relationships are logically interconnected and provide a suitable basis for further testing through regression analysis.

Table 6. Regression analysis (model 2)

Regression Statistics					
Multiple R	0,25562882				
R Square	0,06534609				
Adjusted R Square	0,0585238				
Standard Error	1,12286176				
Observations	277				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	24,15304895	12,0765245	9,57832083	9,5315E-05
Residual	274	345,4642796	1,26081854		
Total	276	369,6173285			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	
Intercept	2,151403	0,383799022	5,60554579	5,0603E-08	
X1	0,14351868	0,073428722	1,95453052	0,0516554	
X2	0,1962472	0,054712175	3,58690186	0,00039618	

Source: own elaboration

The results of the multiple linear regression showed that the model consisting of the variables "Subjective importance of an inclusive environment" (X1) and "Perception of equal opportunities" (X2) is statistically significant as a whole, which means that these factors significantly influence the "Perception of support for students with specific needs" (Y).

The value of the coefficient of determination $R^2 = 0.065$ indicates that approximately 6.5% of the variability in the dependent variable is explained by this model. Although this is not a high proportion, considering the nature of social phenomena, the model can be considered relevant.

From the perspective of individual effects, the strongest predictor is the variable X2 – Perception of equal opportunities (B = 0.1962; $p < 0.001$), which confirms that students who perceive the university as egalitarian are more likely to believe in sufficient support for specific groups. The variable X1 – Subjective importance of an inclusive environment showed borderline statistical significance ($p \approx 0.052$), which indicates a potential but less convincing influence on the dependent variable.

The resulting regression equation is as follows:

$$Y = 2{,}1514 + 0{,}1435\ X1 + 0{,}1962\ X2$$

This result indicates that the concepts of inclusion and equal opportunities are not only value-based but also quantitatively linked to how students evaluate specific university measures concerning the support of vulnerable groups.

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2025 Volume 13 Number 2 (December)
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Based on statistical analyses, it was possible to verify all proposed hypotheses in the context of two separate models.

Evaluation of hypotheses

	Hypothesis Formulation	Result
H1	Perception of the quality of relationships with teachers positively influences satisfaction with their availability outside of teaching.	C
H2	Perception of the university's care for mental health positively influences satisfaction with the availability of teachers.	C
H3	A combination of positive interpersonal relationships and mental well-being predicts satisfaction with the study environment.	C
H4	The importance of inclusion positively influences the evaluation of university support for students with specific needs.	R
H5	Perception of equal opportunities positively influences the evaluation of support for students with specific needs.	C
H6	A combination of the perception of inclusion and equal opportunities is a significant predictor of the perception of university support.	C

Legend: C – confirmed (the hypothesis was statistically supported) **R** – rejected (the hypothesis was not statistically supported)

Within Model 1, which focused on factors influencing students' satisfaction with the availability of teachers, all hypotheses were confirmed. It was shown that both the perception of the quality of relationships with teachers and the perception of care for mental health have individually a statistically significant positive impact on student satisfaction. Likewise, their combined effect was confirmed as a significant predictor. These findings confirm that psychological and interpersonal aspects of the university environment play a crucial role in how students evaluate the accessibility and support provided by teachers.

In the case of Model 2, which examined the relationship between the perception of inclusiveness and the perception of support for students with specific needs, the results were more differentiated. Hypothesis H4, which assumed a direct effect of the subjective importance of inclusion, was not confirmed – the statistical significance of this variable was borderline. In contrast, Hypothesis H5, concerning the perception of equal opportunities, was confirmed, highlighting that the specific perception of the university's fair approach plays an important role in the perception of its support for vulnerable groups. Hypothesis H6 was also confirmed, demonstrating that the combination of both factors (inclusion and equal opportunities) significantly predicts the evaluation of university support.

The overall results thus indicate that social justice, equality, and trust in relationships are key factors shaping students' attitudes toward the university environment. The findings also reveal a difference in the strength of the effect between value orientation (such as the importance of inclusion) and the perception of actual behavior (such as equal opportunities), which is important in terms of applying the results to university management practice.

5. Discussion

The obtained results offer a comprehensive view of how Generation Z students perceive selected aspects of the academic environment – particularly the quality of interpersonal relationships, the availability of pedagogical support, mental well-being, as well as issues of inclusion and equal opportunities. The aim of the research was to examine how Generation Z students perceive the quality of interpersonal relationships and inclusive conditions at the university, and how these dimensions affect their satisfaction with the academic and support environment.

In connection with the first research question (RQ1: What factors influence students' satisfaction with the availability of teachers and interpersonal relationships at the university?), it was confirmed that students' satisfaction with the availability of teachers is significantly influenced primarily by the quality of relationships with instructors, and this influence is positive. Students who rated these relationships as high-quality also showed a higher level of satisfaction with the availability of pedagogical support outside of teaching. The

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2025 Volume 13 Number 2 (December)
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variable related to care for mental health also had a significant impact, although its effect was more moderate. These results are in line with existing findings that a positive academic climate and the emotional availability of teachers play a key role in shaping student engagement and overall satisfaction (Prananto et al., 2025; Di Lisio et al., 2025).

The second research question (RQ2: What factors influence the perception of university support for students with specific needs and minorities?) focused on identifying the factors that influence the perception of university support for disadvantaged student groups. Here, it was shown that the dominant predictor is the perception of equal opportunities. Respondents who perceived the university as a fair and egalitarian institution more often reported that the university provides adequate support for students with specific needs. In contrast, the subjective importance of an inclusive environment was not a statistically significant predictor, which suggests that a value-based belief in the importance of inclusion alone may not be sufficient to reflect in the evaluation of actual support measures. This gap between normative attitude and practical experience is also confirmed by research from Khoo et al. (2024) and Hitches et al. (2024), who point out the insufficient translation of inclusive strategies into concrete everyday practice.

In terms of the complexity of the results, it can be stated that in the case of satisfaction with the availability of teachers, the decisive factor is the quality of interpersonal relationships and the overall impression of care from the university. In the case of the perception of support for disadvantaged students, the key role is played by the specific belief in justice and equal opportunities in the academic environment. The comparison of both models suggests that while interpersonal and psychological dimensions are crucial for students' everyday experience, institutional questions of equality have a greater impact on the perception of systemic support. These findings also point to the different nature of the influence of value-based and functional aspects of academic life, where the importance of inclusion as a norm does not always automatically predict a positive evaluation of university policies. Similarly, research from the workplace environment confirms that trust is a key mediating factor between organizational practices and the feeling of satisfaction – which can also be applied to the academic environment, where trust in the fairness and care of the university fundamentally influences the perception of support (Jaškevičiūtė et al., 2021).

From a practical perspective, the research suggests several recommendations that could contribute to increasing student satisfaction and improving the university environment. First and foremost, universities should systematically support the development of interpersonal relationships between students and teachers – not only through formal educational interactions but also by promoting informal communication, supervision, and training focused on the interpersonal competencies of instructors. The quality of these relationships has proven to be a key predictor of satisfaction with pedagogical availability. The importance of supporting interpersonal ties is also confirmed by the research of Zhang et al. (2024), according to which the quality of relationships and psychological capital play an important role in the overall well-being of university students. In addition, care for mental health should be understood as part of institutional culture, not merely as a supplementary service. Preventive programs focused on mental well-being should be accessible, actively promoted, and respectful of the digital preferences of the current generation.

It is equally essential that the declared values of inclusion be transformed into concrete measures that are understandable and visible to students. Universities should transparently communicate the available support mechanisms and regularly monitor the perception of fairness among different groups of students. According to the results, the experience of equal opportunities has a greater impact on the evaluation of university support than the abstract importance students attribute to inclusion. In this context, it would be beneficial to develop individualized forms of assistance for students with diverse needs, in accordance with the principles of universal design for learning. It is also important to ensure continuity of support throughout the entire course of study, including the first years and transitional periods, which tend to be the most psychologically demanding.

In the future, it would be appropriate to consider expanding the research to include additional psychological and organizational variables, such as academic stress, sense of belonging, quality of teaching, or experiences with systemic barriers. At the same time, it would be beneficial to complement the quantitative findings with qualitative accounts from students, which could offer a deeper insight into the subjective interpretations of the

university environment. There is also the possibility of comparisons between multiple institutions or countries, which would allow for testing the universality of the identified relationships and their contextual specificity.

Conclusions

This study focused on analyzing the factors that influence Generation Z students' satisfaction with the academic and support environment at the university, with particular attention given to interpersonal relationships, mental well-being, and inclusive conditions. Based on two models, it was shown that interpersonal relationships with teachers, the perception of care for mental health, and equal opportunities represent significant predictors of student satisfaction.

The results of Model 1 confirm that students who positively perceive the quality of relationships with teachers and the university's care for their mental health are more satisfied with the availability of instructors. The findings thus support the importance of the emotional availability of teachers and the anchoring of mental well-being as part of university culture. Model 2 showed that while the value of inclusion alone is not a sufficient predictor of satisfaction, the perception of equal opportunities plays a key role in evaluating the specific support provided by the university for students with specific needs. The combination of both factors represents the most significant predictor of support perceived as fair and targeted.

The findings of this study confirm that students' subjective experience is not only a reflection of their individual attitudes but also a result of the quality of interactions and the systemic conditions created by the university. It follows that academic institutions should place emphasis not only on the formal aspects of teaching but also on the social dimension of the university environment – from relationships between instructors and students to structured support mechanisms for various student groups.

For university practice, this implies the need to strengthen training in the interpersonal competencies of teachers, implement sustainable programs focused on students' mental well-being, and ensure transparency and visibility of inclusive measures. From a research perspective, it would be appropriate to expand the analysis to include additional variables, such as feelings of belonging, academic stress, or qualitative accounts from students, which can offer deeper context and interpretation of the quantitative findings. There is also room for comparative studies between different types of universities or within an international framework.

Overall, it can be stated that a university environment that actively supports quality interpersonal relationships, mental well-being, and equal opportunities creates a foundation for more satisfied, engaged, and academically successful student communities.

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EDUCATION AND CAREER TRANSITION OF ATHLETES: A COMPARATIVE ANALYSIS OF FORMER AND CURRENT ATHLETES IN SLOVAKIA*

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Abstract. The article deals with the issue of athlete's career paths and the challenges associated with their transition to civilian professional life after the end of their sporting career. This is a period that is often accompanied by a loss of identity, a change in social status and the need to redefine both professional and personal goals. The aim of the research is to analyse this process, focusing on the importance of education, the development of digital skills and the use of modern technologies. The research is based on a combination of literature analysis and qualitative interviews with current and former athletes. The findings suggest that education is a key factor in a smooth adaptation to the labour market and at the same time boosts athletes' self-confidence in shaping their future career paths. Digitalisation and information and communication technologies are playing a significant role in modernising and personalising the education process, with online courses, flexible curricula and the use of artificial intelligence becoming an integral part of preparing for career transition. The analysis also confirmed the value of transferable skills such as discipline, perseverance, teamwork and stress resilience, which are universally applicable outside of sport. The article highlights the need for a comprehensive approach that links sport, education and career planning using innovative digital tools. The results not only have academic merit, but also provide practical recommendations for sport organisations, educational institutions and policy makers in building effective dual career support systems for athletes.

Keywords: dual career; education; sports management; athletes; digital skills

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1. Introduction

The transition from a sporting career to civilian professional life is one of the key periods that can significantly influence the quality of athletes' later life. It is a process that is often accompanied by a loss of identity, a change in social status and the need to redefine one's professional and personal goals. During their active careers, athletes are used to functioning in a structured environment with clearly defined goals and the support of coaches and a team, which provides stability and security. However, once a career is over, these supports disappear and athletes must cope with new challenges that require the ability to adapt, self-awareness and effective use of the

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experience already gained. This process may vary depending on individual predispositions, social support or available development opportunities.

One of the main factors that can facilitate the transition from sport to civilian life is education. During an active career, it provides athletes with the opportunity to broaden their knowledge, acquire professional qualifications and prepare for careers outside sport. At the same time, education boosts self-confidence and opens space to develop critical thinking, reasoning skills or an understanding of important societal issues such as ethical standards, fair pay or safety norms. In recent years, therefore, the importance of dual careers, which allow the simultaneous development of both sporting and academic or professional competences, has been increasingly emphasised. However, the question remains to what extent athletes take advantage of these opportunities, how they evaluate their benefits and what differences can be observed between those who are still active in sport and those who have retired from professional activity.

In addition to education, the skills and qualities that athletes acquire during their active careers form an essential basis for a successful transition to civilian life. These include discipline, resilience under stress, teamwork, leadership and effective pressure management. These competences are universal and have high value outside sport, which confirms the interest of employers in former athletes. Nevertheless, athletes may differ in which skills they consider key and how they are able to use them in new professional contexts. Comparing the perceptions of these competencies between current and former athletes provides valuable insights into how sporting experience translates into the civilian environment.

Part of the issue is also the readiness of the athletes themselves for the end of their careers. While some perceive the future with certainty and systematically prepare for its arrival, others approach the topic only at the point when career termination is inevitable, which can lead to difficulties in adaptation. Differences in preparation strategies are therefore an important area of investigation as they may signal not only different levels of self-awareness but also different levels of support from clubs, sports federations or institutional programmes.

Thus, a comprehensive analysis of athletes' preparedness, the importance of education throughout their careers, and the applicability of skills acquired through sport provides not only academic contributions but also practical recommendations for sport organisations, universities and public policy makers. The results of such research can contribute to the design of effective support mechanisms that enable athletes not only to successfully complete their active careers but also to fully realise their potential in other professional and life domains.

2. Theoretical background

The term 'sporting career' is used to explore the life trajectory of an athlete and to analyse different dimensions of their life such as sport, leisure or education (Graham et al., 2006; Roberts et al., 2009; Hughes et al., 2021).

Competitive sport is an important factor shaping the career path of athletes. Intense training, discipline and the long-term challenge of pushing one's own limits contribute to the development of skills that have spill-over beyond the sporting environment. Individual understanding of athletes and support in the transition from a professional career to new roles in life and work are therefore essential. The key is to guide them so that they can effectively capitalise on the knowledge and experience gained during active participation and transfer this to other career areas (Andres, 2023; McKnight et al., 2009).

Top athletes possess specific characteristics that represent a competitive advantage in the labour market. Among the most prominent are mental resilience, self-confidence and the ability to focus even in challenging situations (Stambulova et al., 2021). Systematically delivering high performance, perseverance and confidence in one's own abilities are universally valued qualities (Richardson & McKenna, 2020). Athletes also bring a winning mentality to the work environment that makes them attractive candidates for employers (Tarricone & Luca, 2022).

Equally important is the ability to collaborate and lead a team, which creates synergy and competitive advantage in the business sphere (Holubcik & Soviar, 2021; Holubcik et. al., 2023; Celse et. al., 2017). The study by

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2025 Volume 13 Number 2 (December)
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Kniffin et al. (2015) confirms that sporting activity during studies positively influences future career growth, success rates and earning potential. Athletes are perceived as individuals with strong leadership skills, higher self-confidence and self-esteem, which facilitates their employment outside the sporting environment.

In terms of the career paths of former athletes, it is interesting to observe the diversity of their career paths. Research by Buchholz (2019) shows that they most often choose entrepreneurship or work in small companies, while immediately after their careers are dominated by coaching or sports-media professions. However, over the longer term, the proportion of those working in non-profit organizations or corporations increases. This points to the ability of athletes to adapt to different sectors and to use their experience in a broader professional context.

Education is an essential prerequisite for a successful career transition. It provides not only professional knowledge and qualifications, but also soft skills - reasoning, conflict resolution or networking (Dwyer & Gellock, 2018; Stambulova et al., 2021; Stambulova & Harwood, 2022). Moreover, the business environment shows that investment in education yields increased performance (Kucharčíková et al., 2023), which also applies to athletes. Therefore, dual careers that combine sport and education have been shown to be an effective way to promote post-active employment (Brown et al., 2019; Vitali et al., 2019). This relationship can also be evaluated in terms of the social and cultural capital that athletes acquire through education (Johansen et al., 2024).

Creativity, working with finance and digital technologies are considered important skills needed for the future (Blašková et al., 2022; Klieštik et al., 2022; Koman et al., 2023). Modern approaches, such as the use of big data and artificial intelligence to support learning, can further contribute to athletes becoming adaptive professionals ready for the changing demands of the labour market (Sustarsic et al., 2022). Thus, appropriate preparation for transition from sport involves not only formal education but also long-term planning, reflection on life experiences, networking and soft skills development (Vidal-Vilaplana et al., 2022; Brassard et al., 2023).

A smooth and successful career transition for athletes depends on the ability to identify the value of their strengths and use them effectively in new roles. Self-awareness, emotional resilience and the ability to apply transferable skills form the foundation of their future career path (McKnight et al., 2009). Supporting athletes in this area is therefore important not only for their personal development but also for the wider social and economic context.

Previous studies have highlighted the importance of education, transferable skills and personality traits in athletes' transition to a new career path, but the available literature is still inconsistent and lacks direct comparisons between active and former athletes. This gap makes it difficult to understand how readiness for life after sport changes over time and what differences exist in the perception of education, resilience or usability of skills acquired through sport according to career stage. For this reason, the study aims to compare the views of current and former athletes in Slovakia on their readiness for career transition, the role of education in this process and the transferability of sports experiences to professional life.

Based on the above findings, it is pertinent to explore how perceptions of post-career readiness differ between current and former athletes, to what extent education during the active years influences a smooth transition into civilian working life, and to what extent skills and qualities acquired through sport are universally applicable in professional life. These questions follow naturally from the theoretical background and allow for a better understanding of the factors that promote successful careers for athletes after they have retired from active participation.

3. Research objective and methodology

Primary research was conducted on two samples of respondents, which were former athletes (n = 14) and current athletes (n = 30). The inclusion criterion for the research was that sport accounted for some part of their income, regardless of the type of sport or the level at which they played it. The former athletes were also assumed to have completed their active career and be in the process of a civilian career, whereas the current athletes were in an active sporting career.

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2025 Volume 13 Number 2 (December)
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The aim of the research is to compare the experiences of former and current athletes in preparing for the end of a professional sporting career, focusing on the importance of education, perceptions of the conditions for personal and professional development, and the identification of key skills acquired through sport that are applicable in civilian working life.

The specific objectives are:

a. To analyse how current athletes plan their careers after retiring from active sport and how this process is retrospectively evaluated by former athletes.
b. To examine the importance of education during the sporting career and its impact on the smoothness of the career transition.
c. Identify and compare the key skills and qualities that athletes consider transferable to civilian working life.

Data collection was conducted using a structured interview technique (Petersson et al., 2022). The interviews were conducted between February and April 2025 in person and through the online platforms Messenger, Instagram and WhatsApp. Respondents answered orally, in writing or via voice recordings depending on the form of communication. The interviews focused on a number of thematic areas: basic demographics (age, gender, type of sport, career length and level, education), proportion of income from sporting activity, reflection on readiness to leave a sporting career, attitudes to learning during their career and areas of further educational interest, learning opportunities and conditions, retrospective insights into what respondents would do differently, and identification of key skills and attributes acquired through a sporting career and their applicability in later life.

Qualitative content analysis was used to process and analyse the data (Graneheim et al., 2017). The interviews were re-read and key meaning units were identified from the interviews, which were then coded and thematically grouped with the support of artificial intelligence. The results were then interpreted and integrated directly into the analytic text, explicitly stating that this was information from the interviews.

Hypotheses and research questions

Based on the available data from interviews with current and former athletes, three hypotheses were formulated, each with two research questions.

H1: *Current athletes declare a higher level of readiness to retire than former athletes*.

This hypothesis was derived from the assumption that current athletes nowadays have more accessible information, wider educational opportunities as well as a greater societal emphasis on pursuing a career after sport. For former athletes who retired from their careers several years ago, systematic preparation for transition was often lacking. Thus, the hypothesis tests whether there is a difference between groups in how they perceive their readiness for career ending and transition to civilian life.

RQ 1.1: *How do current athletes perceive their future career path after retirement compared to former athletes?*
RQ 1.2: *What differences exist in transition preparation strategies between current and former athletes?*

The answer to this hypothesis and questions is to show whether the athletes' approach to future planning has changed and whether the current generation is better prepared in this respect.

H2: *Education during a career is a key factor that influences the smooth transition of athletes into civilian working life*.

Education has traditionally been seen as a tool for social mobility and, in the case of athletes, it represents a safety net after the end of a career (Robnik et al., 2022). We know from the experiences of former athletes that the absence of education makes it difficult to find a job, while its presence eases the transition (Varmus et al., 2025;). In turn, current athletes often have more flexible opportunities to study during their careers (De Maio,

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2025; Stambulova & Harwood, 2022; Stambulova et. al. Al., 2021; Dwyer & Gellock, 2018). This hypothesis therefore examines whether there is a clear relationship between education and ease of employment after career exit.

RQ 2.1: *What areas of education during their careers do athletes find most beneficial to their career?*
RQ 2.2: *What is the difference in the assessment of the importance of education between current and former athletes?*

This part of the research aims to show whether education makes a real difference to athletes' adaptation and whether current athletes use it more consciously than their predecessors.

H3: *Athletes perceive key skills and qualities acquired through sport as universally applicable to their professional lives, regardless of whether they are current or former athletes*.

Sport naturally develops qualities such as discipline, perseverance, the ability to work in a team or manage stress (Varmus et al., 2025; Martín-Rodríguez et al., 2024; Eather, 2021; Richardson & McKenna, 2020; Celse et al., 2017). This hypothesis is based on the assumption that these 'soft skills' are valuable outside of sport, and that there will be no fundamental difference in perceptions between former and current athletes. Differences might only occur in the hierarchy of importance (e.g., former athletes might emphasize leadership, whereas current athletes are more likely to emphasize discipline).

RQ 3.1: *Which skills and qualities acquired through sport do athletes consider most important for their professional life?*
RQ 3.2: *Are there differences in the hierarchy of perceived skills between current and former athletes?*

The aim is to show that sport experience has long-term value and creates universal competences that increase employability in the labour market.

The research methodology is coherently summarised in a conceptual model, which is illustrated in the following figure.

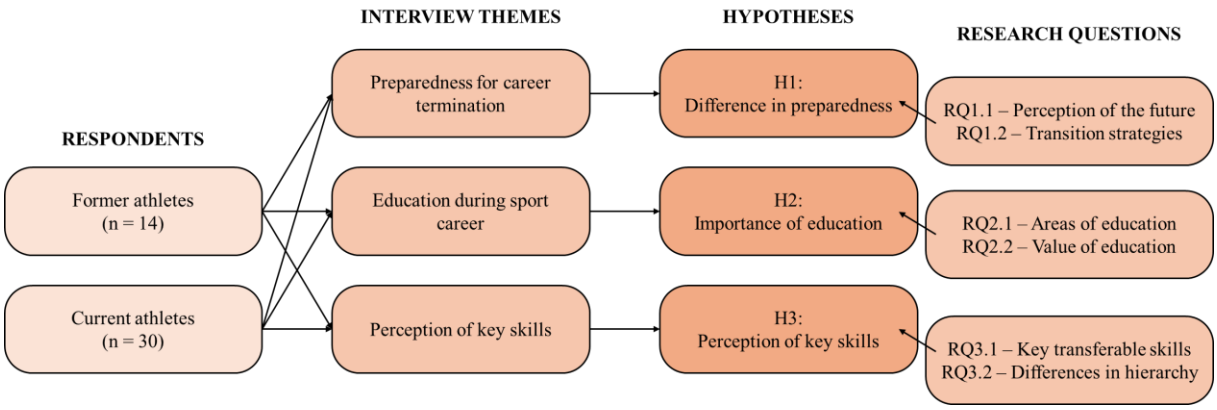


Figure 1. Conceptual Model of the Research

Source: Own elaboration

4. Results

The research sample consisted of 44 respondents who were divided into two groups: former athletes (n = 14) and current athletes (n = 30). The criterion for inclusion in both groups was that sport accounted for some part of their income, regardless of sport discipline or performance level. The age range of respondents ranged from 19 to 45 years. The former athletes were predominantly aged between 30 and 40 years, corresponding to the

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2025 Volume 13 Number 2 (December)
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phase after the end of their professional career and integration into the civilian profession. Current athletes were mostly younger (19 - 30 years old), active at national or international level. Both groups included athletes from individual and team sports, with football, hockey, athletics, swimming, fitness and combat sports being mainly represented. The average length of sporting careers for the former athlete's group was 12 years, and for the current athletes 8 years, reflecting their different position in the career cycle. The educational background of the respondents varied from high school to university, with a higher proportion of the current athletes studying at university. The profile of the sample makes for a good comparison between athletes who have already made the transition to civilian life and those who are yet to make it. In the following sections, we therefore present the results of the analysis of the interviews, focusing on readiness for retirement, the importance of education and the transferability of sport skills.

The analysis of interviews with 14 former and 30 current athletes revealed several differences but also commonalities in how both groups approach their sporting careers and life after retirement. In terms of readiness for retirement, most of current athletes reported that they were already actively thinking about their future outside of sport. Eighteen of them (60%) explicitly stated that they were preparing for a career transition, mentioning combining studies with sport, gaining work experience or planning to obtain coaching licenses. In contrast, former athletes reflected a rather uncertain situation. Only six of them (42.9%) reported that they had thought about their future during their career, while the majority described the transition as sudden or problematic. They often highlighted uncertainty, the need to supplement their education and the absence of systematic support during the transition. In terms of post-career direction, former athletes were almost evenly split between careers in sport (coaching, club management) and careers outside sport (business, armed forces, education, service). Current athletes were more likely to declare an interest in staying in sport, but a significant proportion also mentioned business, IT or marketing as alternative career paths.

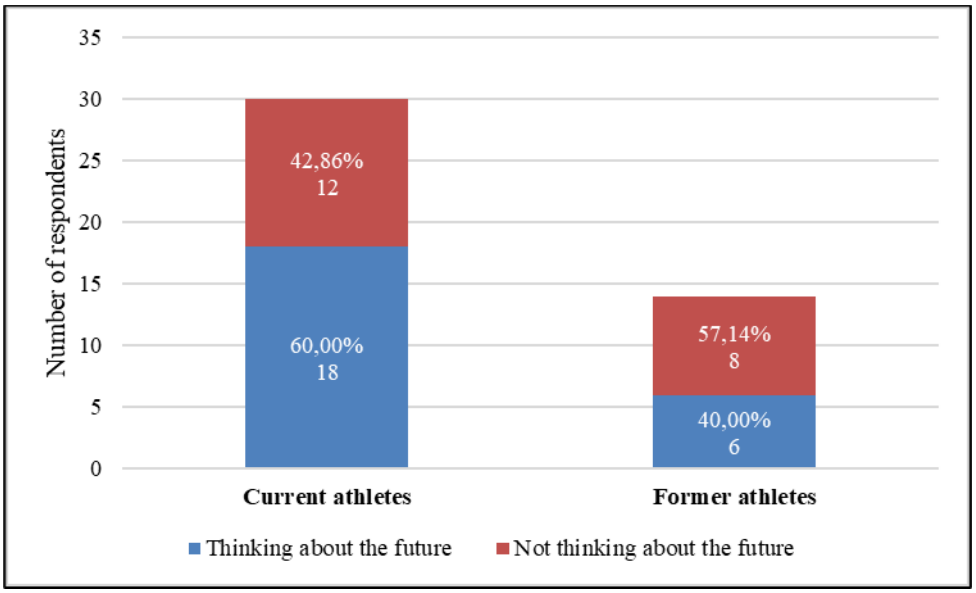


Figure 2. Preparedness for Career Transition – Current vs. Former Athletes

Source: Own elaboration

Education emerged as a key area in both groups. When asked if they had thought about education for future employment during their careers, 42.9% of former and 43.3% of current athletes answered in the affirmative. However, the narrative responses suggest that actual involvement in education was higher, as many described studying or taking courses even without an unequivocal 'yes'. The difference between the groups was more pronounced in the conditions for learning. Only six former athletes (42.9%) said they had favourable opportunities, while this was up to 46.7% among current athletes, highlighting flexible timetables, online courses or individual study plans. Areas of education were varied, but coaching licenses, psychology, physical therapy, management and marketing, IT, healthy eating, and finance came up frequently. In addition,

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/f7779629685

contemporary athletes placed more emphasis on online learning, digital skills and psychology. When asked what they would change about their preparation, the majority in both groups said nothing. Yet, there were recurring reflections that they should have started planning earlier, focused more on foreign languages, or strengthened financial literacy and entrepreneurial skills. These retrospectives were particularly common among former athletes, who openly described difficulties in entering the labour market.

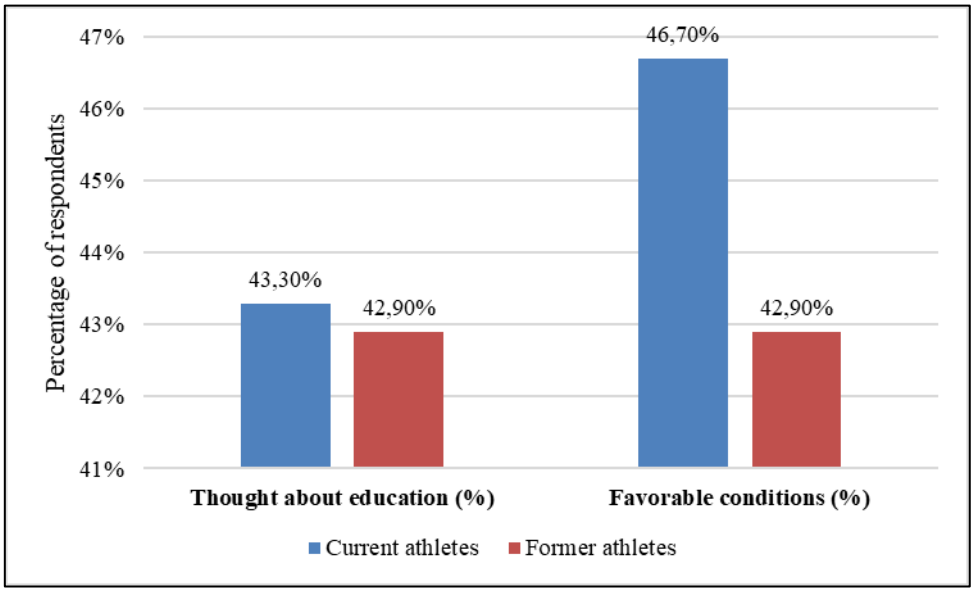


Figure 3. Education during Career – Current vs. Former Athletes

Source: Own elaboration

Transferable skills acquired through sport was another area in which both sets agreed. Respondents clearly perceived sport as a source of competences valuable outside the sporting environment. Teamwork (approximately 28 mentions), discipline (17), perseverance (15), and goal-orientedness (9) were mentioned most frequently. Punctuality and responsibility were also mentioned by several athletes. Differences between the groups were more evident in the hierarchy of importance: former athletes placed more emphasis on teamwork, discipline and self-confidence, whereas current athletes emphasized perseverance, discipline and goal-orientedness. Flexibility, mental resilience, precision, communication or independence also featured less frequently, but nonetheless. There was a consensus in both groups that these skills are fully applicable outside of sport, with differences reflecting career stage rather than differing perceptions of their value.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
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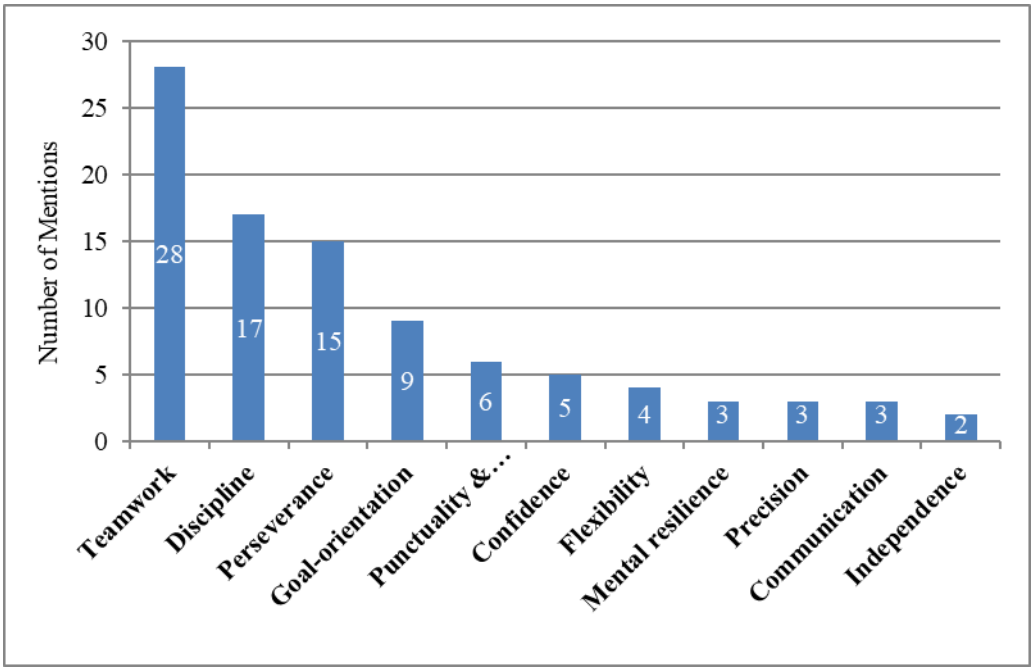


Figure 4. Key Transferable Skills Identified by Athletes

Source: Own elaboration

An additional finding was the share of income from sport. Only a minority of respondents reported it (five former and six current). In this subsample, former athletes achieved a median of 100% of income from sport, while current athletes achieved 85%. This suggests that sport was the main source of livelihood for both groups, underlining the importance of career transition planning and the importance of education in securing a future career.

The research findings show that current athletes are more proactive in terms of preparing for career transition than their predecessors, mainly due to better training conditions and more flexible study options. Conversely, the experiences of former athletes highlight the consequences of under-preparation, and their reflections can serve as a warning for the next generation. However, both groups strongly emphasise the value of the skills acquired through sport and their applicability to future careers. Differences are particularly evident in the ranking they give to each skill. The results thus provide consistent support for the hypotheses formulated, while also providing more subtle insights into how education, preparedness and transferable skills influence each other in shaping athletes' career transitions.

Verification of hypotheses and research questions

Based on the presented results, the individual hypotheses and research questions can be evaluated as follows:

H1: Current athletes declare a higher level of readiness to retire than former athletes.
This hypothesis was confirmed. RQ1.1 showed that current athletes are much more realistic about their future career paths than former athletes, who often reflected unpreparedness. RQ1.2 revealed fundamental differences in strategies; while former athletes addressed the transition after their careers, current athletes plan for it during their careers.

H2: Education during your career is a key factor for a smooth transition to civilian working life.
The hypothesis was confirmed. RQ2.1 showed that the most important areas are coaching licenses, psychology, management, IT and finance. RQ2.2 showed a difference in the importance ratings of training. Former athletes retrospectively see its absence as a barrier; current athletes use it purposefully as an investment in the future.

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2025 Volume 13 Number 2 (December)
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H3: Athletes perceive key skills acquired through sport as universally applicable to professional life.
The hypothesis was confirmed. RQ3.1 showed that teamwork, discipline, perseverance, and goal-orientedness are the most valued. RQ3.2 confirmed that differences between groups exist only in hierarchy, as former athletes emphasize self-confidence and leadership while current athletes emphasize discipline and goal-orientedness.

5. Discussion

These findings support Hypothesis H3 about the universal value of sport skills but also show that their use and perception changes with career stage.

Hypothesis H1, positing a greater readiness of current athletes to exit their careers, was supported on multiple levels. Six out of fourteen former athletes reported thinking about the future during their careers, compared to eighteen out of thirty current athletes. In addition to the quantitative difference, qualitative aspects also emerged. Younger athletes are actively planning, combining sport with studies, preparing alternative scenarios (coaching, business, IT). Former athletes were more likely to describe transition as a reaction to career termination, rather than as a pre-directed process. Thus, research highlights the importance of early planning, investment in education and digital competencies that can mitigate the stress associated with transitioning to a new professional role (McKnight et al., 2009; Andres, 2023). The research confirmed several theoretical assumptions regarding sport careers and the transition to civilian life. As suggested by career path models, athletes may follow a linear, convergent, or parallel career path. In the research conducted, these trajectories were clearly reflected. In most cases, former athletes had a linear profile, and thus sport was the dominant activity, and they only addressed the issues of education or further professional future after their active careers were over. They often described the transition to the civilian profession as abrupt, associated with uncertainty and the need for additional education. Conversely, current athletes more often showed signs of a convergent and parallel path. Studying alongside sport, obtaining coaching licenses, taking online courses, or working odd jobs were common strategies that allowed them to think about the future while still active. This difference is consistent with trends highlighting the importance of dual careers and broader social and cultural capital (Brown et al., 2019; Johansen et al., 2024).

The results also show that most of athletes consider education to be crucial not only during their active years but also after their careers have ended, being fully aware of its benefits when entering the labour market (Asensio Castañeda et al., 2023). This view supports hypothesis H2, which confirms that education is a significant factor for a smooth career transition. Almost the same proportion of former (42.9%) and current athletes (43.3%) reported that they thought about education during their careers, with the younger group having better conditions, i.e., availability of individual plans, online education, or greater tolerance of sports organizations towards learning. The fields of study were varied: coaching, psychology, management, IT, finance or healthy lifestyle.

One of the main challenges in the current preparation of athletes is the mastery of information and communication technology (ICT), which plays a key role not only in the professional environment, but also in education itself (Štaffenová & Kucharčíková, 2023; Štaffenová et al., 2025). The introduction of digital tools has been shown to modernise and improve the learning process (Sulym et al., 2023; Tsarova, 2023). Today's athletes, who have better access to technology, are more likely to use online platforms, cloud-based solutions and mobile applications. Approaches such as the application of Big Data and Artificial Intelligence (AI) offer opportunities for personalised learning, increased training efficiency and better adaptation to changing demands (Miciak et al., 2025; Zhao, 2025). AI-driven chatbots, virtual reality or data analytics are becoming other important tools that allow athletes to gain knowledge and train skills flexibly (Zhao, 2025). These findings extend theoretical assumptions (Sustarsic et al., 2022; Kucharčíková et al., 2023) and suggest that the ability to work with modern technologies is becoming an integral part of athletes' dual careers.

Interesting differences also emerged in the perception of transferable skills. Consistent with theory (Stambulova et al., 2021; Richardson & McKenna, 2020), respondents in both groups viewed sport as a source of valuable competencies such as teamwork, discipline, perseverance and goal-orientation. However, analysis of the interviews revealed different emphases. Former athletes emphasized leadership, teamwork and self-confidence, which is probably related to their current work environment and experience in leading people. Current athletes

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2025 Volume 13 Number 2 (December)
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placed more emphasis on goal-orientation, discipline, and mental toughness, qualities that help them perform well in their active careers.

The results show that education, planning and digital readiness are interlinked and form the basis of a successful career transition. Better learning conditions, openness to parallel pathways and the ability to work with modern technologies allow today's athletes to respond more flexibly to the challenges of the labour market. The experiences of former athletes, on the other hand, remind us of the need for targeted support and learning strategies that enable them to better assess their specific competences in new environments.

Conclusions

The article presents a comprehensive view on the issue of sports career, dual career and transition to civilian life after the end of active sports activity. The results highlight that education, its flexible forms and the use of information and communication technologies play a key role in preparing athletes for future careers. The work thus responds to the need to combine sporting, educational and technological approaches, while also highlighting the trend towards a wider diversification of career paths that go beyond the traditional fields of sport and coaching. This approach is relevant not only for athletes, but also for sport managers, educational institutions, employers and policy makers who can better tailor support programmes and dual career systems based on the results.

The research results fill the identified gap by directly comparing the experiences and attitudes of current and former athletes towards preparing for a career transition. They show that active athletes declare a higher level of readiness for life after their career, which is related to their active planning, combining sports with studies and using digital learning opportunities. Former athletes, on the other hand, more often described the transition as sudden and associated with uncertainty, which indicates the need for targeted support in the period after the end of sports activity. The findings confirm the importance of education and digital competences in mitigating the stress of the transition, which is in line with the claims of McKnight et al. (2009) or Andres (2023).

The novelty of the study lies in the detailed comparison of both groups, which reveals not only different readiness, but also differences in the understanding of education and the use of skills acquired through sports. Education has been shown to be a key factor for a smooth transition to civilian employment, with the younger generation better positioned to develop it thanks to the availability of online platforms and a more tolerant approach by sports organizations (Asensio Castañeda et al., 2023). Transferable skills such as discipline, determination, and teamwork were confirmed in line with previous research (Stambulova et al., 2021; Richardson & McKenna, 2020), but the emphasis varied by career stage – former athletes emphasized leadership and collaboration, while current athletes valued mental toughness and performance orientation more. These findings point to the need for tailored support for different career stages.

The main limitations include the relatively small research sample, which limits the possibilities to generalise the findings broadly. The research relied on a combination of quantitative and qualitative data, but the timeframe only captures the current state and does not consider the long-term development of athletes' career strategies. In addition, some of the data was based on the subjective statements of the respondents, which may introduce a degree of bias. From a technological perspective, it is possible that rapid developments in artificial intelligence, big data and digital tools will cause some recommendations to require updating in the future.

Future studies should work with larger and more diverse samples to account for differences between sport disciplines, performance levels or cultural contexts. It is recommended that research be conducted to better track the planning and transition process throughout the sporting career. It is also interesting to further explore technological aspects, e.g. the specific impact of artificial intelligence, virtual reality or chatbots on athletes' learning and competence development. There is also scope for exploring the collaboration between sports organisations, universities and employers in developing personalised training plans and support systems that reflect the dynamics of the labour market and the individual needs of athletes.

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FOUR-STAGE INCUBATION MODEL FOR UNIVERSITY INNOVATION AND ENTREPRENEURSHIP INCUBATOR: AN EMPIRICAL STUDY*

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Abstract. Aiming at the problems such as service homogenization and ambiguous stage intervention in current university innovation and entrepreneurship incubation platforms, this research constructs a four-stage incubation model of "seedling selection - seedling planting - seedling cultivation - seedling transplantation". Grounded in the resource-based theory, life cycle theory, and service-dominant logic, this study uses 130 projects from the incubation platform of Guangzhou Vocational and Technical University of Science and Technology as samples and conducts empirical tests through methods such as multiple linear regression and hierarchical regression. The results indicate that the core service elements in each stage (for example, the precision of creative screening in the seedling selection stage and the technical resource support in the seedling planting stage) have a significantly positive impact on the outputs of the corresponding stage (such as the passing rate and the prototype iteration speed). The stage assessment mechanism plays a positive moderating role in the service transmission effect. This model has increased the three-year survival rate of projects by nearly 20 percentage points. This research offers references for improving the theory of university incubation and enhancing the practical effectiveness.

Keywords: university innovation and entrepreneurship incubation platform; entrepreneurship incubator; incubation model; resource allocation, incubation performance; empirical study

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JEL Classifications: O3, L26

1. Introduction

Against the backdrop of the in - depth implementation of the national "mass entrepreneurship and innovation" strategy, university innovation and entrepreneurship incubation platforms, as crucial nodes linking the education chain, talent chain, and industrial chain, have made the upgrading of their functions and the innovation of their

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2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/f3646974228

models the core propositions for enhancing the effectiveness of entrepreneurship cultivation (Houssou et al., 2024).

At present, most platforms face structural issues such as homogeneous services and ambiguous stage - based interventions. The traditional "one - size - fits - all supply" model, by overlooking the differential requirements of the project life cycle, results in resource misallocation and low incubation efficiency (Morales-Alonso et al., 2024). Therefore, constructing a "four - stage" incubation model and addressing the above - mentioned dilemmas through systematic resource allocation and dynamic service mechanisms not only provides theoretical support for improving platform efficiency but also offers practical pathways for the deep integration of university innovation and entrepreneurship education with industrial practice, thus holding significant theoretical and practical significance (Yan, Yu & Chen, 2024).

Regarding the current research landscape, abroad, models represented by Y Combinator's "accelerator" and Silicon Valley incubators have established a stage - based cultivation paradigm grounded in the enterprise life cycle, emphasizing market - driven forces and network collaboration. In contrast, domestic research mainly focuses on platform function positioning, resource supply, and performance evaluation. However, it mostly remains at the level of case summaries, suffering from limitations such as fragmented stage categorization and a lack of systematic empirical validation (Crammond et al., 2022). In view of this, this study is based on the university incubation context and aims to develop an integrated "four - stage" theoretical framework to fill the gaps in existing research.

2. Theoretical Foundation and the Construction of the "Four - Stage" Incubation Model

2.1 Definition of Core Concepts

The innovation and entrepreneurship incubation platform in universities is a comprehensive innovation - oriented organization (Gatto & Rusciano, 2023; Yovera et al., 2025). Relying on the scientific research resources and talent advantages of universities, it offers physical spaces, policy support, financial assistance, and management consulting services for the entrepreneurial projects of teachers and students. Its core function is to enhance the survival rate and growth potential of projects through resource integration and value reconstruction (Wang, 2024).

As the structural framework of the platform's operation, the incubation model encompasses a full - cycle support mechanism, from the germination of ideas to the implementation of projects (Sohail et al., 2023). The "Four - Stage" incubation model follows the logical sequence of "seed stage - incubation stage - acceleration stage - maturity stage", enabling phased progress and resource alignment throughout the entrepreneurial process (Li et al., 2025).

Incubation performance, serving as the core metric for evaluating effectiveness, includes both "soft outcomes" (such as enhanced entrepreneurial capabilities and increased team cohesion, which are intangible values) and "hard outcomes" (such as the number of registered enterprises and the scale of financing, which are tangible outputs) (Azadnia et al., 2022).

These three elements - platform, model, and performance - form a logical closed - loop: the platform serves as the carrier, the model acts as the mechanism, and performance represents the outcome. Together, they constitute the core components of the university innovation and entrepreneurship ecosystem (Joshi et al., 2024).

It is important to note that with the evolution of the new technological revolution, the evaluation of incubation performance has become more multi - dimensional and dynamic. This necessitates that the platform's mechanism design incorporates cross - disciplinary perspectives and the ability to adapt to different situations (Yang, Jiang & Zeng, 2024). Therefore, research on the "Four - Stage" model not only enriches the theory of entrepreneurship management but also provides practical guidance for the transformation of university scientific and technological achievements.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/f3646974228

2.2 Theoretical Foundation

The construction of the "Four - Stage" incubation model is underpinned by the resource - based theory, the life - cycle theory, and the service - dominant logic. These three theories form a theoretical triangle from different perspectives, offering a systematic basis for mechanism design.

The resource-based theory posits that an organization's competitive advantage emanates from heterogeneous resources and capabilities, which must be valuable and scarce. The tangible resources (such as laboratory equipment and office space) and intangible resources (such as intellectual property and alumni networks) of university incubation platforms exhibit heterogeneity, which forms the basis of differentiated service capabilities. The efficiency of resource integration directly impacts project growth (Hassan, 2024). This theory emphasizes that the platform should dynamically transition from a "resource provider" to a "resource orchestrator", meeting the evolving needs of projects through cross - boundary integration. This provides theoretical support for the resource - adaptation mechanism of the "Four - Stage" model (Kaggwa et al, 2024).

The life - cycle theory posits that organizational development is characterized by distinct stages, each of which requires tailored strategies (Yasin & Gilani, 2023). When applied to the entrepreneurial domain, it helps to deconstruct the evolutionary patterns of projects. During the seed stage, basic services are essential; in the incubation stage, technical iteration support is crucial; the acceleration stage demands supply - chain resources; and the maturity stage requires high - end services such as IPO guidance (Laspia et al., 2021). This provides a logical basis for the stage division of the "Four - Stage" model, highlighting the need for the platform to break away from a one - size - fits - all approach and enhance the precision of incubation through a stepped resource supply (Marcon & Ribeiro, 2021).

The service - dominant logic emphasizes that value is co - created through interactions among subjects. The platform is not merely a passive resource dispenser but an active participant in value co - creation (Dzingirai, 2025). The quality of its services is manifested in three aspects: interactivity (regular communication to understand needs), empowerment (transfer of knowledge to enhance team capabilities), and synergy (the establishment of a multi - party service ecosystem). This theory guides the platform to shift from a reactive stance to proactive design of service scenarios, establishing a value - co - creation chain that spans the entire project cycle in each stage (Jaakkola et al, 2024).

The organic integration of these theories provides systematic guidance for the stage division, service design, and mechanism construction of the "Four - Stage" model.

2.3 Framework of the "Four - Stage" Incubation Model

Based on the stage - division logic of the life - cycle theory, in conjunction with the resource - matching principle of the resource - based theory and the value - co - creation mechanism of the service - dominant logic, this study constructs a full - cycle cultivation system that spans from the germination of ideas to the mature exit of projects. Each stage is characterized by progressive goal - setting, task - focusing, and service - matching.

First Stage: Germination Cultivation Period

The central objective of this stage is to identify potential ideas through systematic screening and to conduct preliminary verification of technical feasibility and business models. The key tasks include assessing the quality of ideas, building the basic capabilities of the entrepreneurial team, and establishing a risk - early - warning mechanism (Siaw & Sarpong, 2021).

The platform offers services centered around "minimizing the cost of entrepreneurial trial - and - error". It organizes idea - development workshops and business - canvas training sessions to enhance the team's ability to translate ideas into practice (Ead et al., 2023). It assigns entrepreneurial mentors to provide one - on - one guidance, thereby overcoming the hurdles in idea implementation. Additionally, it provides shared office spaces and other lightweight physical resources to prevent resource underutilization. At this stage, as the project is in the early stage of team formation, there is a pressing need for intangible resources such as industry knowledge

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/f3646974228

and policy information (Mohamed et al., 2024). The platform should activate the commercialization potential of ideas by supplying basic resources.

Second Stage: Acceleration Incubation Period

The aim of this stage is to propel the project from idea validation to productization, refine the closed - loop design of the business model, and connect with key early - stage resources. The core tasks involve iterative optimization of the product prototype, positioning the target market, and preparing for seed - round or angel - round financing (Zheng, Shi & Jiang, 2022).

The platform's services exhibit a three - dimensional synergy of "technology + capital + market". It opens professional laboratory clusters (such as those in the fields of intelligent manufacturing and digital cultural and creative industries), providing equipment - sharing and technical - testing services (Piccinetti et al., 2023). It hosts investment and financing road shows and entrepreneurship salons to establish connections with capital sources. In cooperation with third - party institutions, it offers industry data and competitor analysis to reduce the costs associated with market exploration (Mukesh et al., 2020). At this stage, having developed a preliminary product prototype, the project's resource requirements shift from knowledge and information to technical equipment and startup capital, thereby posing higher demands on the platform's resource - integration capabilities (Rai, Prasad & Murthy, 2025).

Third Stage: Market Expansion Phase

The central goal of this stage is to achieve small-scale commercial operations. The focus lies in establishing a stable customer base and a revenue model, thereby laying the groundwork for large - scale development. The core tasks encompass the construction of a supply chain system, the enhancement of brand awareness, and the standardization of operational processes (Klofsten et al., 2025).

The platform's services shift towards in-depth intervention characterized by "industry synergy + policy empowerment". Relying on the industry - university - research network, it connects with upstream and downstream enterprises, facilitating the establishment of procurement, production, and distribution channels (Novino, 2023). In collaboration with the government and industry associations, it conducts brand promotion activities, offering support in new media operations and exhibitions. Additionally, it assigns policy application specialists to assist in accessing favorable policies such as the recognition of high - tech enterprises (Yibo & Jiazheng, 2021).

At this stage, although the project has the capacity for sustained revenue generation, it faces challenges such as the expansion of the team's management scope. Thus, it requires professional support from the platform in areas such as management consulting and talent recruitment, which reflects the "empowering" and "synergistic" aspects of the service - dominant logic.

Fourth Stage: Mature Exit Phase

The objective of this stage is to drive the project to complete its market - oriented transformation, enabling independent operation or realizing value through mergers, acquisitions, or going public. The core tasks include optimizing the corporate governance structure, integrating strategic resources, and formulating an exit strategy (Prado & Brauer, 2022).

The platform's services center around "ecosystem integration + long - term assurance". It collaborates with law firms and accounting firms providing equity structure design and financial audit services. Leveraging the university - industry alliance, it connects with industry leaders and strategic investors, promoting technological cooperation or mergers and acquisitions. Moreover, it establishes a tracking mechanism for graduated enterprises, maintaining resource connections via the alumni network to help the project integrate into the regional industrial ecosystem (Tao & Qian, 2023).

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/f3646974228

At this stage, the project has developed a mature business model. The core demand has shifted from "cultivating internal capabilities" to "embedding in the external ecosystem", and the role of the platform has transformed from a "resource provider" to an "ecosystem coordinator".

3. Research Hypotheses and Design

3.1 Proposal of Research Hypotheses

Integrating the four - stage operational process of "seedling selection - seedling planting - seedling nurturing - seedling transplanting" at the base and the characteristics of service data, the following hypotheses are put forward to form a progressive verification chain of "screening - cultivation - growth - survival":

H1: The accuracy of idea screening during the seedling selection stage (e.g., whether it meets the criterion of "integration with majors") and the matching degree of mentors (e.g., the degree of fit between the mentor's research area and the project direction) have a positive impact on the passing rate of projects entering the seedling planting stage. This hypothesis is grounded in the resource - based theory, highlighting that professional screening and pre - stage resource matching can mitigate the blindness of subsequent cultivation.

H2: The technical resource support during the seedling planting stage (e.g., the frequency of using the creative experiment and processing park) and the participation in entrepreneurship training (e.g., the attendance rate of SYB training) have a positive influence on the iteration speed of the project prototype. Technical resources fulfill the requirements of transforming ideas into physical forms, and standardized training enhances the team's execution ability. The synergy of these two factors promotes product transformation, which is consistent with the resource matching requirements of the germination stage in the life cycle theory.

H3: The supply chain connection during the seedling nurturing stage (e.g., the number of times resources from school - enterprise cooperation bases are utilized) and policy application services (e.g., the number of completed intellectual property agency tasks) have a positive effect on the first - year revenue scale of the project. Supply chain resources expedite the commercialization process, and policy services reduce compliance costs, thereby forming a "resource - benefit" conversion loop, which validates the ecological synergy value of the service - dominant logic.

H4: The strategic guidance during the seedling transplanting stage (e.g., the number of equity optimization services) and the graduation tracking service (e.g., the frequency of quarterly follow - ups) have a positive impact on the three - year survival rate of the project. Strategic guidance strengthens the project's market adaptability, and the tracking service maintains the resource network, facilitating the project's transition from the incubation phase to the industrial phase, which aligns with the "resource orchestrator" position in the resource - based theory.

H5: The stage assessment mechanism of the base (e.g., the passing rate of semi - annual assessments) has a positive moderating effect on the transmission effect of services in each stage. Scientific assessment criteria can enhance the targeting of services. By optimizing resource allocation efficiency through dynamic feedback, it improves the quality of the "service input - output performance" conversion.

3.2 Variable Design

3.2.1 Independent Variables

Centering on the core service elements of the four stages, quantifiable indicators are employed (see Table 1). The data are sourced from the base's service ledgers and project archives:

（1）Seedling Selection Stage

Accuracy of idea screening (X1): The proportion of projects meeting the criterion of "integration with majors". Mentor matching degree (X2): The proportion of projects where the mentor's research area aligns with the project direction.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/f3646974228

（2） Seedling Planting Stage

Technical resource support (X3): The average monthly usage hours of the creative experiment and processing park (in hours).
Participation in entrepreneurship training (X4): The attendance rate of SYB training.

（3） Seedling Nurturing Stage

Supply chain connection (X5): The average monthly number of times resources from school - enterprise cooperation bases are utilized.
Policy application services (X6): The number of completed intellectual property agency tasks (in pieces).

（4） Seedling Transplanting Stage

Strategic guidance (X7): The number of completed equity optimization services.
Graduation tracking service (X8): The actual execution rate of quarterly follow - ups.

3.2.2 Dependent Variables
Corresponding to the output effects of each stage, the data are obtained from the project progress tracking system and annual reports:

(1) Seedling Selection Stage:

The passing rate of projects entering the seedling planting stage (Y1), calculated as (the number of projects entering the seedling planting stage / the total number of projects in the seedling selection stage) × 100%.

(2) Seedling Planting Stage

The iteration speed of the project prototype (Y2), measured as the average number of prototype iterations per week.

(3) Seedling Nurturing Stage

The first - year revenue scale of the project (Y3).

(4) Seedling Transplanting Stage

The three - year survival rate of the project (Y4), calculated as (the number of projects still in existence after three years / the total number of projects in the seedling transplanting stage) × 100%. The survival criterion is continuous operation with stable revenue.

3.2.3 Moderating Variables
The stage assessment mechanism(M), measured by the "semi - annual assessment passing rate", calculated as (the number of projects passing the assessment / the total number of projects participating in the assessment) × 100%. The passing criterion is a comprehensive score of 80 or above. The data are sourced from the base's quarterly assessment score sheets.

3.2.4 Control Variables
Project characteristic variables that may influence the incubation effect are selected:
Project team size (C1): The number of core members, classified as small, medium, or large.
Project industry (C2): High - tech industry, cultural and creative industry, modern service industry, or others (assigned using dummy variables).

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/f3646974228

Project leader's educational background (C3): Junior college or below (assigned a value of 1), bachelor's degree (assigned a value of 2), master's degree or above (assigned a value of 3).

Table 1. Summary table of the classification and numbering of variables related to project incubation

Independent Variables (X)	**Dependent Variables (Y)**	**Moderating Variables（M）**	**Control Variables（C)**
X1：Accuracy of idea screening	Y1：The passing rate of projects entering the seedling planting stage	M：The stage assessment mechanism	C1：Project team size C2：Project industry C3：Project leader's educational background
X2：Mentor matching degree			
X3：Technical resource support	Y2：The iteration speed of the project prototype		
X4：Participation in entrepreneurship training			
X5：Supply chain connection	Y3：The first - year revenue scale of the project		
X6：Policy application services			
X7：Strategic guidance	Y4：The three - year survival rate of the project		
X8：Graduation tracking service			

Source: the authors

3.3 Research Conceptual Framework

This study is based on the four-stage operational process and service data characteristics of the base, namely "seedling selection, seedling production, seedling cultivation, and seedling transplantation," and constructs a progressive verification chain encompassing four key phases: "screening, cultivation, growth, and survival." By formulating five research hypotheses (H1–H5), the study examines the influence of core service elements (independent variables) at each stage on the project output outcomes (dependent variables), while also considering the moderating effect of the stage assessment mechanism and the potential influence of project-specific variables. The conceptual framework diagram presented below clearly illustrates the interrelationships among the variables (see Figure 1).

ENTREPRENEURSHIP AND SUSTAINABILITY ISSUES
ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/f3646974228

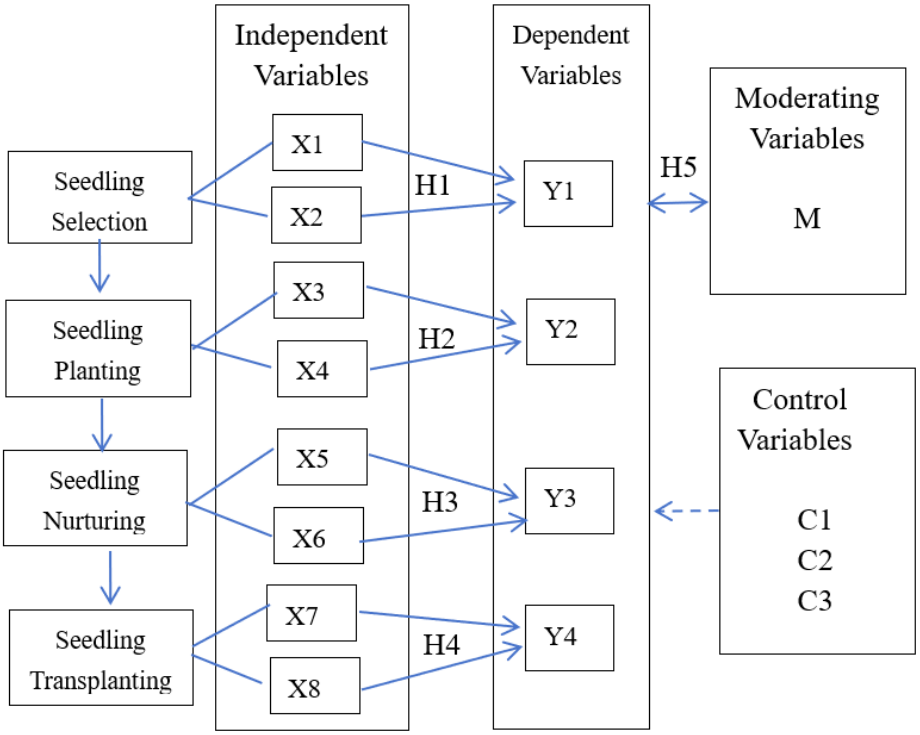


Figure 1. Conceptual framework of the research
Source: the authors

3.4 Data Sources and Sample Selection

The empirical data for this study are sourced from the annual statistical reports of the Innovation and Entrepreneurship Incubation Platform of Guangzhou Vocational and Technical University of Science and Technology spanning from 2020 to 2024. These reports are complemented by first - hand materials such as platform service ledgers, project archives, and assessment records.

Since its establishment in 2012, the base has developed a comprehensive and systematic data - recording system for incubation activities. This system encompasses a wide range of core indicators, including project entry information, detailed service provisions, stage - assessment results, and overall incubation outcomes. These indicators are highly congruent with the variable design of this research.

The sample selection criteria are as follows:

（1） The project must have undergone at least one complete incubation stage, and there should be clear and detailed service records as well as output data within the statistical period. This requirement ensures that the data collected are relevant and sufficient for analysis.

（2） Projects that terminated due to non - natural reasons, such as violations or voluntary withdrawal, are excluded. This exclusion is crucial to minimize potential biases in the data and ensure the integrity of the analysis.

（3） The sample should cover a diverse range of industries and team sizes. This diversity helps to enhance the generalizability of the research findings and reflects the real - world complexity of entrepreneurial projects within the incubation platform.

After a careful selection process, a total of 130 valid samples were identified. Among these, 42 samples are from the seedling selection stage, 35 from the seedling stage, 31 from the seedling cultivation stage, and 22 from the seedling transplantation stage (see Table 2). The sample size meets the requirements for conducting multiple regression analysis, providing a sufficient basis for reliable statistical inferences.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/f3646974228

The time span of the samples covers the mature operational period of the base after it was recognized as a Demonstration Base in Guangzhou in 2014. By including data from different years, the study takes into account the potential impact of varying annual policies and market conditions, thus enhancing the robustness of the research conclusions.

Table 2. Distribution table of the characteristics of 130 valid samples from the innovation and entrepreneurship incubation platform of Guangzhou Vocational and Technical University of Science and Technology

Sample Characteristics	Classification	Quantity (units)	Percentage (%)
Stage Distribution	Seedling Selection Stage	42	32.3
	Seedling Stage	35	26.9
	Nursery Stage	31	23.8
	Transplanting Stage	22	16.9
	Total	130	100
Team Size	Small-sized (1 - 3 persons)	41	31.5
	Medium-sized (4 - 6 persons)	76	58.4
	Large-sized (7 persons and above)	13	10.0
Industry Affiliation	High-tech Industry	42	32.3
	Cultural and Creative Industry	37	28.5
	Modern Service Industry	33	25.4
	Others	18	13.8
Educational Background of the Person in Charge	Junior College and Below	26	20.0
	Bachelor's Degree	88	67.7
	Master's Degree and Above	16	12.3

Source: the authors

3.5 Reliability, Validity Tests, and Analysis Methods

3.5.1 Reliability Test

The reliability test focuses on the internal consistency and stability of the data.

For continuous variables, such as the duration of laboratory usage and the scale of revenue, the intra - class correlation coefficient (ICC) is employed to evaluate stability. An ICC value greater than 0.7 indicates a high level of internal consistency, suggesting that the data are reliable and stable over time.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/f3646974228

For categorical variables, such as whether a project meets the screening criteria, the reliability is verified by checking the consistency between the dual - track records on the platform, namely the service ledgers and the project self - assessment reports. A match rate of at least 90% is considered to indicate reliable data.

In addition, three experts in the field of incubation management conducted cross - validation on 10% of the samples. The resulting agreement rate of 92% further validates the credibility of the data, providing an additional layer of assurance regarding the accuracy and consistency of the dataset.

3.5.2 Validity Test

Content Validity: Content validity is ensured through a combination of theoretical alignment and practical relevance. The design of variable indicators is strictly based on established theoretical frameworks, such as the resource - based theory. Moreover, it takes into account the "Assessment System for Admitted Projects" of the base (for example, the screening criterion of "integration with majors"). This approach ensures that the variables are directly relevant to the research objectives and accurately measure the constructs of interest.

Structural Validity: For multi - dimensional variables, such as "technical resource support in the seedling stage", exploratory factor analysis is performed. The results show a Kaiser - Meyer - Olkin (KMO) value of 0.82, indicating a good sampling adequacy. The Bartlett's test of sphericity is highly significant ($p < 0.001$), suggesting that the variables are inter - correlated and suitable for factor analysis. Additionally, the communalities of all factors are greater than 0.6, which is in line with theoretical expectations, further supporting the structural validity of the variables.

Criterion - related Validity: Criterion - related validity is established by comparing the project operation records with the statistical data. This comparison confirms that the selected indicators can effectively and accurately reflect the actual impact and outcomes of the services provided by the incubation platform.

3.5.3 Analysis Methods

A multi - level statistical analysis approach is employed to test the research hypotheses:

（1）Descriptive Statistics: Descriptive statistics are used to provide an overview of the data, including the mean, standard deviation, and distribution characteristics of each variable. This initial analysis helps to understand the basic properties of the dataset and identify any potential outliers or unusual patterns.

（2）Correlation Analysis: Pearson correlation coefficients are calculated to assess the degree of association between variables. This analysis is crucial for identifying potential relationships between the independent and dependent variables and for detecting any issues of multicollinearity. In this study, the variance inflation factor (VIF) for all variables is less than 3, indicating an acceptable level of multicollinearity and ensuring the reliability of the regression results.

（3）Multiple Linear Regression: Multiple linear regression models are constructed with the outputs of each incubation stage as the dependent variables and the corresponding service elements as the independent variables. Control variables are also included in the models to account for potential confounding factors. This analysis is used to test the main effects of hypotheses H1 - H4, examining how the independent variables directly influence the dependent variables.

（4）Hierarchical Regression: Hierarchical regression is employed to test the moderating effect proposed in hypothesis H5. In this analysis, interaction terms between the moderating variables and the independent variables are introduced into the regression model. This allows for an examination of whether the relationship between the independent and dependent variables is influenced by the moderating variable.

All statistical analyses are conducted using SPSS 26.0 software, and the significance level is set at $p < 0.05$. This threshold is used to determine the statistical significance of the results, ensuring that any observed relationships are not due to chance (see Table 3).

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/f3646974228

Table 3. Tabulation of reliability and validity test results

Test Type	Test Content / Indicators	Specific Results
Reliability Test	Stability of Continuous Variables (ICC)	The ICC of laboratory usage duration is 0.82, and the ICC of revenue scale is 0.79. Both are greater than 0.75, indicating excellent consistency.
	Concordance Rate of Dual - track Records for Categorical Variables	The concordance rate is 93.6%. Since it is greater than or equal to 90%, it is considered reliable.
	Consistency Rate of Cross - validation by Experts	The cross - validation consistency rate of 10% of the samples by three experts in the field of incubation management reaches 92%.
Validity Test	Content Validity	The variable indicators are based on frameworks such as the resource - based theory and refer to the "Assessment System for Incubated Projects" of the base, which is consistent with the research objectives.
	Structural Validity (KMO Value)	The KMO value is 0.82.
	Structural Validity (Bartlett's Test of Sphericity)	The p - value is less than 0.001, indicating a significant test result.
	Structural Validity (Communalities)	All values are greater than 0.6, meeting the theoretical expectations.
	Criterion - related Validity	The correlation coefficients between service variables at each stage and their corresponding outputs are all greater than 0.5 ($p < 0.01$), which can effectively reflect the actual effects of services.

Source: the authors

4. Empirical Results and Analysis

4.1 Descriptive Statistics

The statistical analysis of variables for the 130 samples reveals the following results:

In the seedling selection stage, the mean accuracy of creative screening is 0.78 (SD = 0.15). This indicates a high level of implementation of the "integration with professional fields" criterion by the base, which is consistent with its positioning of cultivating projects rooted in professional disciplines. The mean mentor matching degree is 0.69 (SD = 0.21), suggesting that a majority of projects receive guidance that aligns with their respective fields.

During the seedling stage, the average monthly usage duration of the laboratory is 18.2 hours (SD = 7.5), and the attendance rate of SYB training is 82.3% (SD = 11.7). These figures demonstrate a relatively high level of utilization of technical resources and participation in training.

In the seedling nurturing stage, the average monthly frequency of accessing school - enterprise cooperation resources is 4.3 times (SD = 1.8), and the average number of completed intellectual property agency tasks is 2.1 (SD = 1.3). This reflects the investment in supply chain - related activities and policy - oriented services.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/f3646974228

For the seedling transplanting stage, the average number of equity optimization services is 1.5 times (SD = 0.8), and the quarterly follow - up execution rate is 89.6% (SD = 9.2), indicating the continuity of strategic guidance and tracking services.

Regarding the dependent variables, the pass rate for the seedling stage is 68.5% (SD = 12.3), the prototype iteration speed is 0.8 times per week (SD = 0.3), the first - year revenue amounts to 526,000 yuan (SD = 289,000), and the three - year survival rate is 72.3% (SD = 15.6). These values are generally consistent with the base's 75% incubation success rate in 2022.

The moderating variable, the pass rate of the semi - annual assessment, is 76.8% (SD = 10.5). Among the control variables, most teams are small to medium - sized (58.4% have 4 - 6 members). The industries represented include high - tech (32.3%) and cultural and creative industries (28.5%). The educational background of project leaders is predominantly a bachelor's degree (67.7%). The structure of the sample is in line with the common characteristics of university - based incubation projects (see Table 4).

Table 4. Table of descriptive statistical results of sample variables

Variable Type	Specific Variable	Mean / Percentage	Standard Deviation (SD)	Unit
Independent Variables	X1	0.78	0.15	-
	X2	0.69	0.21	-
	X3	18.2	7.5	hour(s)
	X4	82.3%	11.7	%
	X5	4.3	1.8	time(s)
	X6	2.1	1.3	item(s)
	X7	1.5	0.8	time(s)
	X8	89.6%	9.2	%
Dependent Variables	Y1	68.5%	12.3	%
	Y2	0.8	0.3	time(s) per week
	Y3	52.6	28.9	ten thousand yuan
	Y4	72.3%	15.6	%
Moderating Variables	M	76.8%	10.5	%
Control Variables	C1	58.4%	-	%
	C2: High-tech industry	32.3%	-	%

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2025 Volume 13 Number 2 (December)
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Variable Type	Specific Variable	Mean / Percentage	Standard Deviation (SD)	Unit
	C2: Cultural and creative industries	28.5%	-	%
	C3	67.7%	-	%

Source: the authors

4.2 Results of Reliability and Validity Tests

The reliability test results show that for continuous variables, the Intra - class Correlation Coefficient (ICC) is greater than 0.75 for all cases. For example, the ICC of laboratory usage duration is 0.82, and that of revenue scale is 0.79, indicating excellent data stability. For categorical variables, the matching rate of dual - track records is 93.6%, and the consistency rate of expert cross - validation is 92%, meeting the requirements for reliability.

In the validity test, exploratory factor analysis yields a Kaiser - Meyer - Olkin (KMO) measure of 0.82 ($p < 0.001$). The factor loadings of all variables are greater than 0.65. For instance, the factor loading of creative screening accuracy is 0.78, and that of supply chain connection is 0.72. The cumulative variance contribution rate is 76.3%, indicating a high degree of congruence between the variable structure and the theoretical framework.

Content validity is verified by ensuring the alignment with the service indicators outlined in the "Administrative Measures for Guangdong Science and Technology Innovation College Students' Entrepreneurship Base". Criterion - related validity is established as the correlation coefficients between service variables at each stage and their corresponding outputs are all greater than 0.5 ($p < 0.01$), further corroborating the reliability of the validity.

4.3 Hypothesis Testing Results

The results of multiple linear regression analysis indicate that:

H1 is supported: In the seedling selection stage, the accuracy of creative screening ($\beta = 0.32$, $p < 0.01$) and the mentor matching degree ($\beta = 0.28$, $p < 0.01$) have a significant positive impact on the pass rate of the seedling stage ($R^2 = 0.41$). This finding indicates that screening for professional relevance and precise mentorship can enhance the project advancement rate.

H2 is supported: During the seedling stage, technical resource support ($\beta = 0.45$, $p < 0.001$) and participation in SYB training ($\beta = 0.23$, $p < 0.05$) have a significant positive influence on the prototype iteration speed ($R^2 = 0.53$). This validates the promotional effect of technical equipment and entrepreneurship training on the productization process.

H3 is supported: In the seedling nurturing stage, supply chain connection ($\beta = 0.36$, $p < 0.01$) and intellectual property agency services ($\beta = 0.29$, $p < 0.01$) have a significant positive impact on the first - year revenue ($R^2 = 0.48$). This suggests that the integration of industrial resources and policy - compliance services can expedite the commercialization process.

H4 is supported: For the seedling transplanting stage, equity optimization services ($\beta = 0.31$, $p < 0.01$) and graduation tracking services ($\beta = 0.35$, $p < 0.01$) significantly improve the three - year survival rate ($R^2 = 0.52$). This confirms the crucial role of strategic guidance and ecosystem maintenance in ensuring the project's long - term survival.

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H5 is supported: The interaction terms between the stage assessment mechanism and services at each stage are all significant (for example, the interaction term with supply chain connection has a β value of 0.18, $p < 0.05$). This indicates that the assessment mechanism can strengthen the service transmission effect (the moderation effect size $\Delta R^2 = 0.07$), see Figure 2 below.

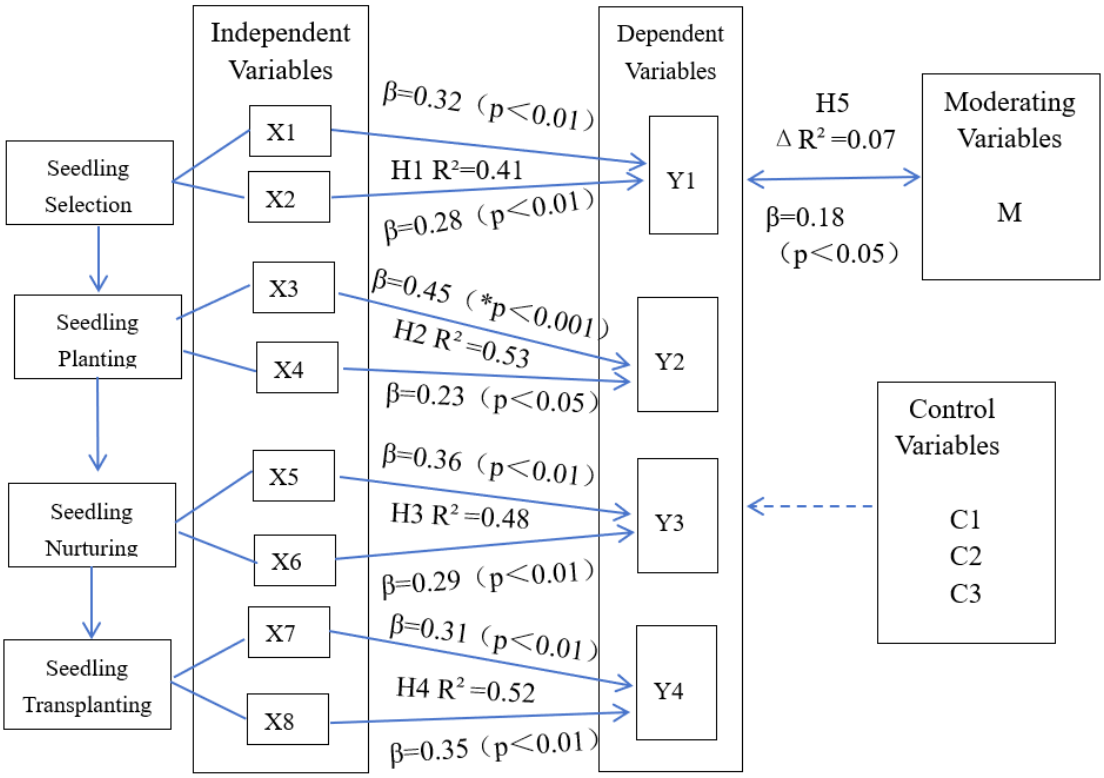


Figure 2. The conceptual framework of the research on regression results
Source: the authors

4.4 Case-based Evidence

Typical cases from the Guangdong Science and Technology Innovation College Students' Entrepreneurship Base further substantiate the effectiveness of the "Four - Stage" model.

Case 1: Seven Colorful Advertising Planning Co., Ltd. (An Alumni - led Project)

During the seedling selection stage, given the high degree of alignment between the project and the major of advertising design and visual communication (screening accuracy = 1), and the successful matching with a mentor in the cultural and media domain (matching degree = 1), the project smoothly advanced to the seedling stage.

In the seedling nurturing stage, by leveraging the school - enterprise resources coordinated by the base, such as those from Guangzhou Daily Printing, the project achieved an average of six monthly connections with the supply chain. Additionally, it completed three trademark registrations. As a result, the project recorded a first - year revenue of 850,000 yuan, thereby validating Hypothesis H3.

In the seedling transplanting stage, the project received two equity optimization services, and the quarterly follow - up implementation rate reached 100%. The company has been operating stably for five years, with a survival rate of 100%, providing support for Hypothesis H4.

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2025 Volume 13 Number 2 (December)
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Case 2: Guangzhou Gesang Flower Art Design Co., Ltd. (A Project by Current Students)

In the seedling stage, the project utilized the experimental processing park for the development of a dry - flower making device, with an average monthly usage of 25 hours. All team members actively participated in the SYB training, achieving an attendance rate of 95%. Consequently, the project completed three prototype iterations within three months, with an iteration speed of 1.0 times per week, thus verifying Hypothesis H2.

Since the project met the requirements of the semi - annual assessment (scoring 89 points), the base increased its resource allocation in favor of this project. This led to the establishment of a connection with the flower farmer supply chain in Yunnan, enabling the project to achieve a first - year revenue exceeding 600,000 yuan. This case exemplifies the moderating effect of the assessment mechanism, as postulated in Hypothesis H5.

Both cases illustrate that the progressive provision of services across the four stages is highly congruent with the growth requirements of the projects, thereby corroborating the empirical findings.

5. Discussion and Conclusions

5.1 Dialogue between Research Findings and Theories

The findings of this study resonate profoundly with the resource - based theory. The resource - based theory accentuates the decisive role of the precise allocation of heterogeneous resources in establishing an organization's competitive edge. The four - stage model of "seedling selection, seedling planting, seedling nurturing, and seedling transplantation" validates the applicability of this theory within the incubation context through the dynamic alignment of resources with demands at each stage. For instance, in the seedling - planting stage, technical laboratory resources are provided, and in the seedling - nurturing stage, supply - chain resources are made available.

Specifically, "professional - fit screening" during the seedling - selection stage ($\beta = 0.32$) and "equity - optimization services" in the seedling - transplantation stage ($\beta = 0.31$) significantly enhance the incubation outcomes through the strategic allocation of heterogeneous resources. This finding corroborates the transformation logic of the platform from a mere "resource provider" to a more sophisticated "resource orchestrator".

The interaction with the life - cycle theory is manifested in the scientific approach to stage delineation. The life - cycle theory posits that organizations experience distinct demand variations across different developmental stages. The four - stage progressive design accurately captures the evolving needs of projects. For example, in the seedling - planting stage, there is an acute need for technological iteration, as evidenced by the correlation coefficient of 0.68 between the prototype iteration speed and the duration of laboratory use. In the seedling - nurturing stage, the project shows a strong reliance on supply - chain and policy resources, as indicated by the correlation ($\beta = 0.36$) between the first - year revenue and the frequency of school - enterprise cooperation. These examples highlight the significance of stage - specific resource alignment, thereby addressing the theoretical limitations of the traditional "one - size - fits - all" service model.

In comparison with existing research on incubation models, the "four - stage" model overcomes the fragmentation issue through its progressive mechanism design. Most previous studies have concentrated on optimizing services within a single stage. However, this study demonstrates that the seamless connectivity between stages (for example, the correlation coefficient of 0.53 between the passing rate from the seedling - selection to the seedling - planting stage and the subsequent prototype iteration speed) significantly influences overall performance. This offers a novel theoretical perspective for resolving practical challenges such as "stage discontinuities" and "resource misallocations".

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5.2 Practical Implications and Future Research Avenues

5.2.1 Practical Implications

At the practical level, the implementation of the "four - stage" model should adhere to the principles of "stage - specific focus, dynamic integration, and precise alignment":

For University Incubation Platforms: During the seedling - selection stage, the screening for "professional fit" should be intensified. For example, the weight of relevant indicators could be increased to 40%. In the seedling - planting stage, resources such as "laboratory access + SYB training" should be bundled. In the seedling - nurturing stage, a collaborative network encompassing "university - enterprise cooperation bases - policy application" should be established. In the seedling - transplantation stage, the mechanisms for "equity optimization - follow - up monitoring" should be refined. Additionally, resource allocation should be adjusted based on semi - annual assessments, with a passing rate of at least 80% triggering preferential resource allocation to strengthen stage - to - stage linkages.

For University Administrators: There is a need to transition from a simplistic "resource accumulation" approach to a more systematic "system - building" strategy. This involves optimizing cross - stage resource repositories by categorizing and integrating internal laboratories, external supply chains, etc., according to different stages. A mentor team with "multi - stage adaptability" should be assembled, where professional mentors are assigned in the seedling - selection stage and mentors with capital - market expertise are introduced in the seedling - transplantation stage. Moreover, project survival rates should be linked to mentor evaluations to establish a dynamic assessment mechanism.

For Incubated Projects: Projects should enhance their awareness of the different stages. In the seedling - planting stage, priority should be given to obtaining laboratory access rights. Mature projects should actively seek to connect with resources available in the seedling - transplantation stage, thereby avoiding the pitfall of attempting to cover all stages without a clear strategy. The case of the Seven Colorful Advertising Company, where precise alignment with nurturing - stage resources led to a 62% higher first - year revenue compared to similar projects, underscores the value of such targeted resource utilization.

5.2.2 Future Research Avenues

Future research can be extended in three main directions:
Cross - regional Comparative Studies: Conduct comparative research across different regions by selecting representative university incubation platforms in the eastern, central, and western parts of the country. This approach can help identify variations in the adaptability of the model under diverse resource endowments.
Longitudinal Data Analysis: Incorporate longitudinal tracking data and utilize panel models to dynamically trace the growth trajectories of projects. This will deepen our understanding of the mechanisms underlying stage - to - stage transitions.

Technology - enabled Innovations: Explore ways to leverage technology, such as the application of artificial intelligence. For example, develop big - data - driven algorithms for automatic stage identification and intelligent resource matching to enhance the precision of services. Additionally, research on the adaptation of the model to specific scenarios, such as intangible cultural heritage related cultural and creative industries or rural revitalization initiatives, can further enrich the theoretical framework.

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GENERATIONAL PREDICTORS OF JOB SATISFACTION IN THE CONTEXT OF FLEXIBLE WORK ARRANGEMENTS*

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Abstract. The aim of this study was to analyze and compare the predictors of job satisfaction in the context of flexible working conditions across Generations X, Y, and Z. The research questions focused on identifying significant factors influencing satisfaction and examining generational differences in their perception. The quantitative research was conducted through an online questionnaire among respondents in Slovakia, with the data analyzed using correlation and multiple regression analysis. The results showed that all the observed generations exhibit statistically significant predictors of job satisfaction, although their structure differs. In Generation X, the most important roles were played by work-life balance and mental health; in Generation Y, motivation and engagement dominated; and Generation Z was influenced by a combination of motivation, psychological well-being, and private life. An important finding was that the variable 'motivation and engagement' had a significant effect across all generations, while the other factors displayed generational specificity. In conclusion, it can be stated that flexible working conditions represent an important tool for supporting employee satisfaction, the effectiveness of which depends on adaptation to the specific needs of individual age cohorts. The research also provides recommendations for the creation of individualized HR strategies reflecting the value-based and lifestyle preferences of different generations of workers.

Keywords: job satisfaction; flexible work arrangements; generational differences; work-life balance; employee motivation

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JEL Classifications: J28, J21, J81, M54, M12

1. Introduction

Flexible working conditions have in recent years become one of the most discussed phenomena in the field of human resource management, mainly due to the changing nature of work, technological progress, and the growing emphasis on work-life balance. The importance of flexibility in the work environment is increasing in connection with employee expectations across generations, and it appears that its proper implementation can

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significantly influence job satisfaction, engagement, and overall employee performance. Various scientific studies confirm that flexible work arrangements can contribute to higher employee satisfaction, primarily through their positive impact on work-life balance as well as the reduction of emotional exhaustion (Indradewa & Prasetio, 2023; Manchidi, 2025). At the same time, however, they point out that the effectiveness of these measures may be influenced by several mediating or moderating factors, such as job stress, subjective improvement of work-life quality, or organizational culture. These conclusions are also supported by a literature review study that identified key factors influencing job performance when working from home, including mental and emotional aspects, gender roles, and the role of technologies in team collaboration (Habánik et al., 2024).

In the context of gender equality and the specific needs of certain groups of employees, it appears that workplace flexibility plays an important role particularly for women. Research from the information and communication technology sector in Southeast Asia confirms that flexible work arrangements positively influence the job satisfaction of female employees, with organizational culture supporting work-life balance also playing a key role. The conflict between work and family responsibilities was identified as a significant mediator of these relationships (Aura & Desiana, 2023). The findings therefore emphasize the need to take cultural and social specificities into account when introducing flexible policies and highlight the importance of building a so-called family-friendly corporate culture.

In addition to job satisfaction, flexible working conditions also significantly contribute to the improvement of work performance. Research conducted in two companies showed that job satisfaction and work-life balance act as important mediators between flexibility and performance. It was particularly confirmed that a positive attitude toward work and a sense of satisfaction increase employee engagement, which leads to higher productivity (Safira & Wahyuningsih, 2024). This model also shows that although flexibility directly influences performance, its effect is amplified when it is part of a comprehensive system supporting employees' psychological and life comfort.

An important aspect in the implementation of flexible regimes is also the broader institutional and cultural context in which the organization operates. Research conducted in 22 countries showed that the effectiveness of so-called flexi-time solutions depends on the degree of cultural 'looseness' and the existence of labor legislation regulating this area. In countries with a stricter culture and without legislative support, the effect of flexibility on absenteeism and turnover appears ambiguous, with these effects being more curved than linear. Conversely, in countries with an open culture and legislative backing, the positive impact of flexible working hours on organizational outcomes is confirmed (Berkery et al., 2024). These findings underline the need to align internal HR policies with the external legislative and cultural environment in which companies operate.

The role of leadership, remuneration, and organizational culture in shaping employee satisfaction cannot be overlooked. Research from the banking sector in Malaysia showed that although flexible working conditions have a positive effect, their effectiveness may be weakened in environments with a rigid culture or inappropriate management style. Transformational leadership and a supportive culture proved to be significant enhancers of the impact of flexible arrangements on employee satisfaction, while the remuneration system played a key role in shaping the overall work attitude (Hasim et al., 2024).

From the above-mentioned research, it is clear that flexible working conditions represent an important factor influencing job satisfaction, performance, and work-life balance. However, their effectiveness depends on several variables — individual, organizational, and cultural. For the effective implementation of flexible regimes, it is therefore essential to take into account not only employee preferences but also the broader context and the value orientation of the organization.

2. Literature review

The flexibility of working conditions and its impact on job satisfaction represents a topic that has attracted extraordinary scientific interest in recent years, especially in the context of generational differences. Several studies collectively suggest that generational cohorts X, Y, and Z welcome and evaluate flexibility to varying

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2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/y4922288422

degrees, which is reflected in their satisfaction, motivation, psychological well-being, and work engagement. Jung and Yoon (2021) pointed out the positive impact of work flexibility on employee engagement and job satisfaction in the hospitality sector, which proved to be especially important for Generation Z, who strongly prefer flexibility. Similarly, Joesah et al. (2025) demonstrated that flexibility increases satisfaction, but its impact on engagement is indirect and mediated by satisfaction. This indicates a complex dynamic between flexibility and work performance among young employees.

In the public administration environment, Pradipta et al. (2025) found that flexibility directly increases the satisfaction of Generation Z, which also leads to better performance. Singh (2023) pointed out that the introduction of flexible working conditions leads to improved employee morale and productivity, although their effectiveness depends on organizational culture and the type of work. These findings are also confirmed by research on micro and small enterprises, which shows that workplace autonomy supported through flexibility can significantly enhance the innovation capacity and adaptability of enterprises (Bujáki & Vinogradov, 2024).

Govender et al. (2018) showed that flexibility strongly correlates with employee satisfaction and performance even in developing countries, mainly due to its ability to support work-life balance. In the industrial environment, Droste (2025) emphasized that although statistical differences between generations in response to flexibility were not strong, generational preferences were evident. In particular, younger employees preferred flexible scheduling.

Baša et al. (2023) found that Generations Y and Z prefer flexible working hours, motivated by the desire for freedom and balance. Conversely, Tshabalala (2022), in an extensive international study, suggests that generational differences in flexibility preferences may not be significant, which indicates the universality of this trend across cultures.

An interesting perspective is offered by Stankiewicz-Mróz (2020), who compares the expectations of employers and representatives of Generation Z, revealing differences in the importance attributed to flexibility. Medina-Garrido et al. (2023) demonstrate that access to flexibility indirectly increases performance through the improvement of psychological well-being, which is consistent with the findings of the author's research. These conclusions are also complemented by the research of Egerová and co-authors (2021), which shows that although generational differences between Generations Y and Z in work expectations do exist, an even more important factor appears to be intra-generational diversity shaped by experience, gender, or geographical environment – which highlights the need for a sensitive and individualized approach in the development of HR policies.

Czerwińska-Lubszczyk and Jankowiak (2025) identified generational differences in motivation and the importance of non-material motivators, which can serve as a basis for diversified HR approaches. These conclusions are also supported by research from Romania, which pointed out that Generation Z is significantly motivated by factors such as recognition, personal appreciation, well-being, and the opportunity for skills development, while these employees also demonstrate lower loyalty toward employers and prefer individual performance over team collaboration (Ivanova et al., 2023; Surugiu et al., 2025). Similarly, Lee et al. (2024) point out the importance of operational and spatial aspects of flexibility in supporting the engagement of young adults.

Russo et al. (2023) showed that independence and autonomy at work are key factors of satisfaction in the context of working from home. Smite et al. (2022), on the other hand, identified a permanent change in the psychological contract between employees and employers, where flexibility ceased to be a benefit and became an expected standard. These findings are complemented by the research of Schall (2019), which demonstrated that remote work positively influences job satisfaction precisely through increased perceived autonomy, lower work-family conflict, and higher telecommuting intensity.

Sun et al. (2023) demonstrated that although employees have preferences regarding the time organization of work, their reality often deviates from these expectations. This underlines the need for individualized approaches. Maya and Londoño (2024) revealed that job satisfaction and autonomy in time management are

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2025 Volume 13 Number 2 (December)
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interconnected, especially in the context of larger companies and longer work experience. This connection is also confirmed by long-term quantitative research (n = 631), according to which respondents with a higher degree of autonomy in work scheduling, decision-making, and the selection of work methods showed significantly higher job satisfaction (Zychová et al., 2024), while the findings also pointed to generational differences.

Akbar and Amalia (2023) focused on the impact of flexibility, support, and family variables on the work-life balance of Generation Z, which demonstrated a multiple effect — not only work-related but also social aspects. Similarly, Deas and Coetzee (2022) confirmed that generations differ in their expectations of the psychological contract, particularly in the area of work-life balance, which reflects the need for differentiated personnel strategies.

Finally, Pacheco (2025) found that the preference for hybrid models increases with the change in work settings, especially among younger employees. Febriana and Mujib (2024) confirmed that flexibility and participatory styles have a significant impact on the productivity of Generation Z, also through emotional engagement.

To summarize, the available literature confirms several aspects of the findings, particularly in the areas of motivation, psychological well-being, and work-life balance as key predictors of job satisfaction. At the same time, it supports the theory that generational differences play a significant role, which requires an adaptive approach in the development of HR strategies.

3. Methodology

The main aim of this scientific article is to analyze and compare the predictors of job satisfaction in the context of flexible working conditions across Generations X, Y, and Z. The research focused on identifying aspects of work flexibility that may manifest differently in relation to the subjective satisfaction of individual generations. Based on this aim, two research questions were formulated:

- **Research Question 1:** Which aspects of the perception of flexible working conditions significantly influence job satisfaction within Generations X, Y, and Z?
- **Research Question 2:** Are there statistically significant differences in the structure and importance of the predictors of job satisfaction among Generations X, Y, and Z?

These research questions were operationalized through two hypotheses:

- **H1:** Within Generations X, Y, and Z there are statistically significant predictors of job satisfaction related to the perception of flexible working conditions.
- **H2:** There are statistically significant differences in the predictors of job satisfaction among Generations X, Y, and Z.

The empirical part of the research was focused on examining the perception of work flexibility and its connections with job satisfaction among respondents from different generations. The questionnaire survey took place in October 2024 in the territory of the Slovak Republic and was conducted in the Slovak language through the MS Forms platform. The distribution was carried out through a combination of several channels: by e-mail, via social networks, within universities, and also in cooperation with employers.

The target group consisted of respondents belonging to Generations X, Y, and Z, with generation identified based on age. The questionnaire contained 17 statements, of which 7 were the subject of analytical modeling. The statements concerned various aspects of work flexibility as well as overall job satisfaction. Responses were recorded using a five-point Likert scale, where 1 expressed complete disagreement and 5 complete agreement with the statement. In total, 83 respondents participated in the survey. Participation was voluntary and anonymous, and respondents were informed about the research purpose of data processing. Based on the above-

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2025 Volume 13 Number 2 (December)
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mentioned research questions and hypotheses, three analytical models were created, with each model corresponding to one generation (X, Y, Z). The dependent variable in all three models was:

- **Y:** Job satisfaction

The independent variables represented six dimensions of the perception of flexibility:

- **X1:** Motivation and engagement
- **X2:** Support from the employer
- **X3:** Social isolation
- **X4:** Stress reduction
- **X5:** Psychological well-being
- **X6**: Work-life balance

Two main analytical methods were used for the analysis of the collected data:

- Correlation analysis was used to determine the direction and strength of relationships between variables.
- Multiple linear regression analysis was applied separately for each generation in order to identify predictors of job satisfaction. Statistical testing was carried out at a significance level of $\alpha = 0.05$.

The modeling was based on the assumptions for the use of linear regression. The normality of the data distribution was verified through the values of skewness and kurtosis. The linearity of the relationships was ensured by the positive wording of the statements, and given the one-time nature of data collection, autocorrelation was excluded. Based on the outputs, no significant multicollinearity was found among the independent variables, which supports the stability of the models.

4. Findings

In the following section, the results of descriptive statistics, correlation, and regression analysis are presented, focusing on the identification of factors influencing job satisfaction in the context of flexible working conditions. The calculations are divided according to three generational groups — X, Y, and Z — in order to capture their different preferences and perceptions of flexibility in the work environment.

Table 1. Descriptive statistics of the observed variables

Generation X							
	X1	*X2*	*X3*	*X4*	*X5*	*X6*	*Y*
Mean	4,33333333	3,777777778	1,88888889	3,22222222	4,111111111	4,22222222	4,44444444
Standard Error	0,32338083	0,400616808	0,36949788	0,42438387	0,369497883	0,32894718	0,31542297
Median	5	5	1	3	5	5	5
Mode	5	5	1	5	5	5	5
Standard Deviation	1,37198868	1,699673171	1,56764675	1,80050828	1,567646752	1,39560468	1,33822632
Kurtosis	2,44375	-0,962965541	0,4432775	-1,808019	0,443277501	1,4045043	3,89653151
Skewness	-1,9132811	-0,903820288	1,44205848	-0,2373882	-1,44205848	-1,6134066	-2,2690455
Generation Y							
	X1	*X2*	*X3*	*X4*	*X5*	*X6*	*Y*
Mean	4,58823529	4,411764706	1,88235294	4,05882353	4,823529412	4,64705882	4,76470588
Standard Error	0,20299736	0,215767283	0,24166942	0,27014612	0,098749654	0,19749931	0,14040192
Median	5	5	1	5	5	5	5
Mode	5	5	1	5	5	5	5
Standard Deviation	1,18366782	1,25812865	1,40916278	1,57520901	0,575804483	1,15160897	0,81867682
Kurtosis	6,05018506	2,881460744	0,4195957	-0,0512177	7,686264308	7,68626431	14,5392712
Skewness	-2,7279677	-2,019301079	1,32532187	-1,2888273	-3,03922608	-3,0392261	-3,7521626
Generation Z							
	X1	*X2*	*X3*	*X4*	*X5*	*X6*	*Y*
Mean	4,22580645	4,032258065	1,83870968	4,48387097	4,741935484	4,29032258	4,48387097
Standard Error	0,2732114	0,3058001	0,28996394	0,20672026	0,153579106	0,25481829	0,2265732
Median	5	5	1	5	5	5	5
Mode	5	5	1	5	5	5	5
Standard Deviation	1,52117668	1,702622898	1,61445087	1,15096967	0,855092273	1,41876821	1,26150618
Kurtosis	0,89234342	-0,354238544	0,34902644	4,0029221	13,02066579	1,53161162	3,96680688
Skewness	-1,6235349	-1,26636643	1,49850067	-2,2014577	-3,56105478	-1,751186	-2,3040846

Source: own elaboration

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2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/y4922288422

As part of the comparison of the three age groups — Generations X, Y, and Z — the basic statistical characteristics of seven variables related to the perception of flexible working conditions were analyzed. The variables included the subjective assessment of job satisfaction (Y) as well as factors such as motivation (X1), support from the employer (X2), social isolation (X3), stress management (X4), psychological well-being (X5), and work-life balance (X6).

The highest average value in Generation X was recorded for variable Y (M = 4.44), which confirms high job satisfaction among respondents when using flexible forms of work. This was followed by variables X1 (M = 4.33), X6 (M = 4.22), and X5 (M = 4.11), indicating that flexibility in this generation is perceived primarily as a tool that increases motivation, well-being, and the ability to balance work with personal life. The lowest ratings appeared for X3 (M = 1.89) and X4 (M = 3.22), with the low score for social isolation suggesting that respondents generally did not perceive this dimension as problematic.

In Generation Y, variable X5 (M = 4.82) dominated, followed by (M = 4.76) and X6 (M = 4.65). Unlike Generation X, well-being associated with flexibility was therefore rated even more strongly, with the high ratings indicating alignment between working conditions and mental comfort. Again, the lowest average value was recorded for variable (M = 1.88), confirming the general trend across groups.

In the case of Generation Z, the highest average was again recorded for variable X5 (M = 4.74), closely followed by variables X4 and Y (both M = 4.48). Generation Z therefore strongly perceives flexibility as a tool for reducing stress and increasing comfort. The lowest values, consistent with the other generations, were recorded for variable X3 (M = 1.84), which again indicates a low occurrence of feelings of social isolation.

From the perspective of variability, in Generation X the most dispersed responses were recorded for X4 (SD = 1.80), which indicates different perceptions of stress. This was followed by X2 and X3 (SD ≈ 1.70), which may be related to individually differing perceptions of support and social relationships. In Generation Y, the highest variability was found for X4 (SD = 1.58), X3 (SD = 1.41), and X2 (SD = 1.26), which again indicates differing perceptions of the interpersonal aspects of flexibility. In Generation Z, the highest standard deviation was recorded for X2 (SD = 1.70), X3 (SD = 1.61), and X1 (SD = 1.52), while the lowest variability was found for X5 (SD = 0.86), which may suggest a general consensus among respondents about the benefits of flexibility for mental health.

As for distribution characteristics, several variables showed significant asymmetry. In all three groups, the variables Y, X1, X5, and X6 were characterized by negative skewness, which indicates a concentration of responses in the higher values of the scale (i.e., strong agreement). Conversely, variable X3 had positive skewness in all cases (e.g., 1.44 in Generation X, 1.33 in Y, 1.50 in Z), which suggests that most respondents reported low values of isolation, but in some cases higher ratings also appeared. The highest kurtosis was recorded in Generation Y for variables Y (14.54) and X5 (7.69), which points to a strong concentration of responses around the highest values.

Overall, it can be stated that the data of all three generations showed mild to pronounced asymmetries and several cases of sharper distributions (leptokurtosis). However, these characteristics do not represent a fundamental disruption in the context of socio-psychological research and the scales used, since the responses logically reflect the preferential distribution of opinions in favor of positively evaluated statements. The variables display consistent patterns within the groups, which creates a solid basis for subsequent comparative regression modeling.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
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Table 2. Correlation analysis

Generation X							
	X1	*X2*	*X3*	*X4*	*X5*	*X6*	*Y*
X1	1						
X2	0,63903915	1					
X3	-0,0364662	0,166802999	1				
X4	0,34925035	0,093972483	0,42607207	1			
X5	0,69285871	0,539656763	0,14893617	0,40754719	1		
X6	0,81923192	0,66680078	0,11949726	0,447383	0,955978057	1	
Y	0,81163977	0,718378941	0,24924174	0,44486448	0,760187322	0,88889467	1
Generation Y							
	X1	*X2*	*X3*	*X4*	*X5*	*X6*	*Y*
X1	1						
X2	0,23939344	1					
X3	-0,0662579	-0,108586211	1				
X4	0,50095694	0,507286148	-0,215215	1			
X5	0,24584428	0,856280963	0,04833076	0,47952774	1		
X6	0,24584428	0,521642426	0,04833076	0,21224998	0,634408602	1	
Y	0,64749656	0,332277415	-0,1297905	0,48102285	0,42351386	0,42351386	1
Generation Z							
	X1	*X2*	*X3*	*X4*	*X5*	*X6*	*Y*
X1	1						
X2	0,42180588	1					
X3	0,16462675	0,11109438	1				
X4	0,14493909	0,280934233	-0,0462933	1			
X5	0,55881893	0,555396886	0,06542723	0,5375332	1		
X6	0,54007643	0,644548639	-0,1971651	0,25812365	0,613336366	1	
Y	0,75757337	0,628780171	0,08869765	0,26956604	0,737643306	0,75698411	1

Source: own elaboration

The aim of the correlation analysis was to identify the relationships between the independent variables (X1–X6) and the dependent variable Y, as well as to assess the extent to which the individual independent variables correlate with each other within the three generations.

In the case of Generation X, strong and positive correlations were found between the dependent variable Y and several independent variables. The strongest correlation was observed with variable X6 (r = 0.89), followed by variables X1 (r = 0.81), X5 (r = 0.76), and X2 (r = 0.72). Variables X4 and X3 showed moderately strong and weak correlations, respectively (r = 0.44 and r = 0.25), which indicates that satisfaction in this group is most closely associated with inner comfort and work-life balance. Interesting it was also the internal structure of the relationships between the independent variables — in particular, the very strong correlation between X5 and

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2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/y4922288422

X6 (r = 0.96), which may signal an overlap in meaning between the perception of psychological well-being and work-life balance. Similarly strong connections appeared between X1 and X6 (r = 0.82), as well as between X1 and X5 (r = 0.69), which points to the interconnectedness of the psychological aspects of the perception of flexibility.

In the case of Generation Y, the highest correlation with satisfaction (Y) was again found with X1 (r = 0.65), followed by variables X4 (r = 0.48) and X5 (r = 0.42). The remaining variables showed only weak relationships with Y, including X2 (r = 0.33) and X6 (r = 0.42). A distinctly weak correlation was found with variable X3 (r = –0.13), which suggests that social isolation in this group is not a significant factor influencing satisfaction.
The strongest correlation between the independent variables was identified between X2 and X5 (r = 0.86), which suggests that in this group, support from the employer is closely related to perceived psychological well-being. Furthermore, moderately strong relationships were also found between X2 and X4 (r = 0.51) and X1 and X4 (r = 0.50). Overall, the structure of relationships between the variables in this group was less pronounced than in Generation X.

In the case of Generation Z, the dependent variable Y was most strongly correlated with X1 (r = 0.76), X6 (r = 0.76), and X5 (r = 0.74). A clear relationship was also observed with X2 (r = 0.63). Similar to other generations, variable X3 correlated with satisfaction only very weakly (r = 0.09), which again confirms the low weight of this dimension in generational perception.

In this group as well, there was a strong correlation between X5 and X6 (r = 0.61) and X2 and X6 (r = 0.64), which reflects the interconnectedness between perceived employer support, psychological well-being, and the ability to balance work and personal life. Correlations among the other variables were less pronounced compared to Generations X and Y. Across all three groups, it was shown that the variables X1 (motivation), X5 (psychological well-being), and X6 (work-life balance) exhibited the strongest correlations with satisfaction (Y). Conversely, X3 — 'Social isolation' — was either insignificant or very weakly associated with satisfaction in all generations, confirming that this aspect does not have key importance in the context of flexible work.

Table 3. Regression analysis

Regression Statistics - Generation X					
Multiple R	0,95951334				
R Square	0,92066586				
Adjusted R Square	0,87739269				
Standard Error	0,46858431				
Observations	18				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	6	28,0291606	4,67152677	21,2756752	1,8779E-05
Residual	11	2,415283843	0,21957126		
Total	17	30,44444444			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	
Intercept	0,19475983	0,411845117	0,4728958	0,64553205	
X1	0,03355167	0,174928217	0,19180253	0,85139163	
X2	-0,0466521	0,120248225	-0,3879651	0,70544459	
X3	0,1981441	0,091758895	2,15939942	0,05376046	
X4	-0,0694323	0,092377245	-0,7516171	0,46805824	
X5	-1,0132096	0,342972343	-2,9542021	0,01311051	
X6	1,9647016	0,522607934	3,75941786	0,00315785	

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2025 Volume 13 Number 2 (December)
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Regression Statistics - Generation Y					
Multiple R	0,73948327				
R Square	0,5468355				
Adjusted R Square	0,44613228				
Standard Error	0,60927803				
Observations	34				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	6	12,09471468	2,01578578	5,43016894	0,000861423
Residual	27	10,02293238	0,37121972		
Total	33	22,11764706			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	
Intercept	0,75400009	1,244117269	0,60605226	0,54954174	
X1	0,34930462	0,105960217	3,29656381	0,00274445	
X2	-0,1750447	0,172566354	-1,0143616	0,31941443	
X3	-0,0721978	0,080918922	-0,8922234	0,38015635	
X4	0,06679165	0,092075251	0,72540282	0,47444583	
X5	0,49644679	0,41612604	1,19302024	0,2432401	
X6	0,13997035	0,122930078	1,13861762	0,26486499	
Regression Statistics - Generation Z					
Multiple R	0,89740851				
R Square	0,80534204				
Adjusted R Square	0,75667755				
Standard Error	0,62227231				
Observations	31				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	6	38,44858753	6,40809792	16,5488639	1,81298E-07
Residual	24	9,293347957	0,38722283		
Total	30	47,74193548			
	Coefficients	*Standard Error*	*t Stat*	*P-value*	
Intercept	-0,2759458	0,670254961	-0,4117027	0,68421106	
X1	0,30146131	0,099643615	3,02539512	0,00584191	
X2	0,07361884	0,094334072	0,78040559	0,44278164	
X3	0,04968593	0,080279941	0,61890839	0,5418073	
X4	-0,0600824	0,120854982	-0,4971443	0,6236111	
X5	0,43435541	0,216038636	2,01054503	0,05573885	
X6	0,30473414	0,132770406	2,29519625	0,03076559	

Source: own elaboration

The aim of the regression analysis was to determine which factors statistically significantly influence respondents' job satisfaction (Y) in the context of flexible working conditions across the three generational cohorts. For each model, the same independent variables X1 to X6 were included, with their relationship to the dependent variable examined separately for Generations X, Y, and Z.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/y4922288422

In the case of Generation X, the model achieved high predictive power, with a coefficient of determination $R^2 = 0.92$, which means that up to 92% of the variability in respondents' satisfaction can be explained by the selected variables. The model was statistically significant ($F = 21.28$; $p < 0.001$) and identified two significant variables: X5 ($\beta = -1.01$; $p = 0.013$) and X6 ($\beta = 1.96$; $p = 0.003$). While X6 had a positive effect on satisfaction, the negative coefficient for X5 may indicate a more complex perception of well-being in this generation — for example, that psychological well-being is already a consequence rather than a determinant of satisfaction. The other variables were not statistically significant.

In Generation Y, the model was also statistically significant ($F = 5.43$; $p < 0.001$), explaining approximately 55% of the variability in satisfaction ($R^2 = 0.55$). In this model, the only statistically significant variable was X1 ($\beta = 0.35$; $p = 0.003$), which suggests that in this age group, satisfaction is primarily derived from a sense of engagement and the possibility of actively influencing one's work schedule. The other variables — including well-being, family time, or employer support — did show positive coefficients but were not significant, which may reflect broader generational variability in needs.

The model for Generation Z reached $R^2 = 0.81$ and was equally highly statistically significant ($F = 16.55$; $p < 0.001$), revealing three significant predictors of satisfaction: X1 ($\beta = 0.30$; $p = 0.006$), X5 ($\beta = 0.43$; $p = 0.056$), and X6 ($\beta = 0.30$; $p = 0.031$). This suggests that the satisfaction of the younger generation is influenced by a broader spectrum of factors – from personal engagement, through psychological well-being, to the ability to balance work and personal life. Although the p-value for variable X5 was slightly above the traditional significance level, considering the context and effect size, it appears to be relevant.

From a comparative perspective, it can be stated that variable X1 was the only one that was significant across all three generations, which confirms its universal importance in shaping job satisfaction. In contrast, X6 was significant only in Generations X and Z, which may reflect different life priorities. Also interesting was the development of the significance of variable X5, which was significant only in the extreme age groups (X and Z), while in Generation Y this factor did not gain statistical support.

Overall, the results suggest that job satisfaction derived from flexibility is a multidimensional phenomenon, the specific determinants of which differ according to age, life stage, and employee expectations. These findings have practical implications for HR professionals and managers, who should individualize flexible conditions according to generational preferences and values.

Table 4. Summary of regression analyses for Y

Generation	*Regression models for Y*
Gen X	Y = 0,0336 X1 - 0,0467 X2 + 0,1981 X3 - 0,0694 X4 - 1,0132 X5 + 1,9647 X6
Gen Y	Y = 0,3493 X1 - 0,1750 X2 - 0,0722 X3 + 0,0668 X4 + 0,4964 X5 + 0,1340 X6
Gen Z	Y = 0,3014 X1 + 0,0736 X2 + 0,0450 X3 - 0,0601 X4 + 0,4344 X5 + 0,3071 X6

Source: own elaboration

Table 4 presents the linear equations of regression models for the three generational groups (X, Y, and Z), with the aim of identifying which factors most significantly influence job satisfaction in the context of flexibility. Based on the calculated linear functions, it can be stated that in Generation X, the factor X6 – "Work-life balance" (coefficient = 1.9647) had the greatest influence, indicating the high sensitivity of this group to the possibility of balancing work and personal life. In the case of Generation Y, the dominant factor was X1 – "Motivation and engagement" (coefficient = 0.3493), confirming that the sense of engagement and autonomy at work is a key aspect in this cohort. In Generation Z, the most significant coefficient was also found for variable X1 (0.3014), but factors X5 – "Psychological well-being" (0.4344) and X6 – "Time for family" (0.3071) also played an important role, together creating a complex picture of generational preferences.

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2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/y4922288422

Table 5. Evaluation of Hypotheses

Hypothesis	*Hypothesis formulation*	*Result*
H1	Within Generation X, Y, Z, there are statistically significant predictors of job satisfaction that are related to the perception of flexible working conditions.	**Confirmed**
H2	There are statistically significant differences between Generations X, Y and Z on predictors of job satisfaction.	**Confirmed**

Source: own elaboration

Within the framework of hypothesis H1, which assumed the existence of statistically significant predictors of job satisfaction within each individual generation, the findings were clearly confirmed. In generation X, the significant factors were psychological well-being (X5) and work-life balance (X6). In generation Y, only motivation and engagement (X1) proved to be a statistically significant predictor. In generation Z, the significance of as many as three predictors was confirmed: motivation and engagement (X1), psychological well-being (X5), and work-life balance (X6). Thus, hypothesis H1 was empirically supported in all three cases.

Hypothesis H2 focused on intergenerational differences in the structure of significant predictors of satisfaction. This hypothesis was also confirmed. While generation Y showed only a single significant factor (X1), generations X and Z were influenced by a broader spectrum of variables. Moreover, the significance of variable X5 (psychological well-being) was negative in generation X, whereas in generation Z it had a positive character, which also indicates a qualitative difference in its perception between the cohorts.

These differences suggest that each generation perceives job satisfaction in relation to flexibility differently, and therefore it is desirable to approach the design of working conditions individually – reflecting the value orientations and life stage of employees.

5. Discussion

The discussion follows up on the research findings and analyzes them in the context of the established objective and research questions. The focus is placed on the identified statistically significant relationships between the observed variables. At the same time, similarities and differences between individual generations, which emerged from the conducted analyses, are reflected.

By answering the first research question – „Which aspects of the perception of flexible working conditions significantly influence job satisfaction within Generations X, Y, and Z?" – it was identified that although statistically significant predictors of satisfaction exist in each generation, their structure differs. In Generation X, the significance of two variables was confirmed – X5 (psychological well-being) and X6 (work-life balance), with X6 having a positive effect on satisfaction, while X5 acted negatively. This paradoxical effect may reflect the complexity of perceiving well-being among older employees – for example, in the sense that mental well-being is not a direct predictor of satisfaction, but its consequence. In Generation Y, the only significant factor turned out to be variable X1 (motivation and engagement), suggesting that for this cohort the key aspect is the feeling of autonomy and meaningfulness of work. Generation Z displayed a broader spectrum of significant predictors – in addition to X1, the importance of X5 (psychological well-being) and X6 (work-life balance) was also confirmed, pointing to the complex balance between inner comfort, personal engagement, and life harmony sought by young employees.

The second research question – „Are there statistically significant differences in the structure and importance of the predictors of job satisfaction among Generations X, Y, and Z?" – was addressed through a comparative analysis of regression models. The results clearly confirmed intergenerational differences. While in Generation Y only one variable was significant, X and Z displayed a wider range of significant factors. Moreover, qualitative differences in the perception of the same variables (e.g., X5) point to the distinct meaning of psychological well-being for each age group. In Generation X, well-being may be the result of a stable work

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regime and personal security, whereas in Generation Z it represents an expected part of working life that young people actively demand.

The findings of the research build upon numerous insights from the available literature. Several studies (e.g., Jung and Yoon, 2021; Pradipta et al., 2025; Govender et al., 2018) demonstrated a strong relationship between flexibility, satisfaction, and mental well-being, particularly among younger cohorts. Significant preferences of Generations Y and Z towards work-life balance were also identified (Baša et al., 2023), which was reflected in the relevance of variable X6. The contribution of this research lies mainly in confirming the generationally differentiated effects of the same variables – particularly X5 and X6 – highlighting the need for individualized HR approaches and the rejection of universal solutions.

From a practical perspective, it is recommended that employers take into account the specifics of individual age groups when setting flexible working conditions. For older employees (Generation X), it is important to support work-life balance through clearly defined work frameworks and the possibility to adapt working hours to personal needs. For Generation Y, priority should be given to creating an environment that supports autonomy and intrinsic motivation. Generation Z expects a comprehensive approach to flexibility – not only in terms of time organization but also regarding psychological support and overall work culture that aligns with their value orientation. Flexibility should therefore not be understood merely as a technical tool but as part of a broader culture of trust, engagement, and respect for the individual needs of employees.

Conclusions

The research results confirmed that flexible working conditions represent a significant determinant of job satisfaction across Generations X, Y, and Z, while individual age cohorts perceive their benefits differently. The analysis showed that each generation responds to different aspects of flexibility, reflecting their life experiences, values, and preferences.

In Generation X, the key factor was the balance between work and private life (X6), which had a positive impact on satisfaction, while psychological well-being (X5) had a negative effect, indicating a more complex way in which older employees perceive workplace well-being. Generation Y attributed the highest importance to motivation and engagement (X1), which relates to their orientation toward meaningfulness of work and inner autonomy. In Generation Z, several factors proved significant – motivation and engagement (X1), psychological well-being (X5), and work-life balance (X6), highlighting their holistic approach to working life.

The findings also confirmed the existence of intergenerational differences in the predictors of satisfaction. Flexible working conditions therefore cannot be perceived as a universal tool suitable for all employees without distinction, but as a system that requires adaptation to individual and generational needs.

Based on these results, several recommendations for practice can be formulated. Organizations, when designing flexible working arrangements, should take into account not only technological or operational possibilities but also the specifics of individual age groups. For older employees, it is appropriate to provide stability and the possibility to better reconcile work and personal commitments.

For younger generations, it is necessary to create an environment that supports autonomy, psychological well-being, and the ability to actively shape their work rhythm. Flexibility should therefore be perceived as a strategic tool whose effectiveness depends on its sensitive and targeted application in line with the value orientation of employees.

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CAPITAL MARKET BEHAVIOR AND STOCK FORECASTING – A NEURAL NETWORK APPROACH TO LUFTHANSA´S SHARES*

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Abstract. The study deals with the development and prediction of stock prices of a selected European airline, Deutsche Lufthansa Group, in the context of its presence on capital markets between 2004 and 2024. The main objective is to analyse the time series of historical daily stock prices of Deutsche Lufthansa Group and use this data to forecast price development in the near future using the method of artificial neural networks in the Statistica 14 software. The study further identifies the key external and internal factors influencing the volatility of the company´s stock, as financial crisis, political unrest, escalation of the European debt crisis, government strikes, acquired parts of other companies, increasing competition from low-cost carriers, growing pressure to reduce CO2 emissions etc. The results show that predictive models based on multiplayer perceptron networks can effectively predict short term development of stock prices in the dynamic environment of capital markets. The results revealed that the prediction for Lufthansa´s share prices show a slightly upward and stable trend. This trend reflects the positive expectation and stabilization of costs, which may indicate renewed investor confidence in the company´s long-term recovery. The findings offer a valuable insight for investors, analysts, and the academic community and can serve as a foundation for further research on stock price prediction in the aviation industry.

Keywords: stocks; capital market; historical prices; airline industry; artificial neural networks; Artificial Intelligence (AI), investment

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1. Introduction

The aviation industry has long been one of the key sectors of the global economy. Its importance goes far beyond tourism – it supports international trade, labor mobility and employment. At the same time, it is a sector that is extremely sensitive to changes in external conditions and must adapt quickly to new trends. In recent decades, the industry has undergone fundamental changes, largely caused by globalization. Consumer preferences are constantly evolving, which forces airlines to innovate services and improve their quality (Adeniran et al., 2023). Air transport is one of the most regulated industries (Gabor et al., 2022) and, despite a temporary slowdown during the COVID-19 pandemic, remains highly competitive. A number of factors influence airlines' pricing and competitive strategies. For example, Ryanair uses competitive advantages in the labor market and legal frameworks (Harvey & Turnbull, 2020). Another strategy is to increase flight frequencies, which can discourage new low-cost carriers without reducing demand (Valido et al., 2020). In an environment with limited airport capacity, it is relatively easy to prevent the entry of competitors, while in higher capacity, access to new carriers

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must be allowed. The significant position of aviation is also conditioned by external influences, which include in particular oil prices, geopolitical events or the characteristics of tourist destinations (Domínguez et al., 2021). Efficient fuel use and fleet modernization also play an increasingly important role, which allow for reducing costs and emissions and increasing the quality of services provided (Oliveira et al., 2021; Oliveira et al., 2022). Accurate ticket pricing is key to ensuring profitability, yet revenue management systems often monitor individual variables separately, without their broader context (Jayram et al., 2023). In addition, ongoing liberalization, privatization, and changing government policies significantly influence airline strategies and the operation of regional airports (Pietreanu, 2019). These factors show that aviation remains one of the most dynamic and vulnerable sectors of the global economy. This dynamic development is inevitably reflected in the capital markets, which represent one of the most important sources of financing for airlines and a means of raising capital for fleet modernization, expansion, or overcoming crisis periods. Airline shares therefore serve not only as an investment tool, but also as a sensitive indicator of the overall health of the industry. Airline share prices are highly sensitive to volatile and cyclical factors, which makes their prediction particularly difficult (Zheng et al., 2021). Nevertheless, their analysis is essential for investors and analysts, as it allows them to better estimate risks and opportunities in an environment that is extremely dynamic and prone to unexpected shocks. For airlines themselves, the development of shares is an important indicator of investor confidence and a factor that affects their ability to raise funds for further growth. Forecasting airline shares therefore has a dual meaning - for markets and investors, it provides a tool for decision-making and portfolio diversification, and for airlines it is a source of strategic information that reflects not only their own economic results, but also the broader macroeconomic and geopolitical environment. Given that aviation is one of the most vulnerable and at the same time the most strategic sectors of the world economy, the issue of forecasting shares is becoming one of the key topics of current research and practice.

The aim of this study is to determine the development of Deutsche Lufthansa Group's stock prices, analyse the historical time series of daily stock prices, and predict future price trends. To achieve this goal, the following research questions were formulated:

- RQ1: What factors have had the greatest impact on the volatility of Deutsche Lufthansa Group's stock prices between 2004 and 2024?
- RQ2: How is Deutsche Lufthansa Group´s stock price expected to evolve during January and February 2025?

2. Theoretical background

Predicting stock market developments has long been considered a very difficult task, mainly due to their inherent nonlinearity and complexity (Nabipour et al., 2020; Wang et al., 2024; Peternel & Bukvič, 2024). The main obstacle is the difficulty of reliably identifying simple patterns in an environment that is highly dynamic and dependent on a wide range of variables (Chi et al., 2022). Although traditional econometric approaches such as regression models, ARIMA or GARCH allow a certain degree of explanation of historical developments, they often encounter limits in capturing nonlinear relationships and complex market dynamics. This significantly limits their ability to generate accurate predictions, especially in an environment characterized by frequent fluctuations and the influence of external factors (Wang et al., 2023).

These limits are being addressed by the increasing use of artificial intelligence and machine learning methods, which have demonstrated high efficiency in analyzing large historical data sets (Vijh et al., 2020). These methods can reveal hidden patterns and relationships that traditional statistical tools often fail to capture. However, historical data alone is not enough to achieve fully reliable results, as financial markets are also shaped by factors that cannot be easily quantified and are difficult to capture even through neural networks (Barra et al., 2020; Katina et al., 2024). The prediction of stock prices is influenced by a wide range of factors - from volatility and recent returns to macroeconomic indicators to public sentiment (Ramezanian et al., 2019; Nti, 2021). Moreover, the growing volume of data generated from different sources increases the complexity of their integration, as individual data streams often have different formats and structures (Khan et al., 2020). In addition to traditional financial and economic variables, less conventional sources of information are also gaining

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importance. Social media and financial news can significantly change investor behavior in a short time, which emphasizes the need to include them in predictive algorithms.

Azzolina et al. (2021) state that the factors influencing the development of airline stock prices are extremely diverse. These include primarily fuel prices, which constitute a significant part of airlines' operating costs, as well as macroeconomic indicators such as GDP growth or inflation, as well as geopolitical events that can affect both air transport demand and operating costs. According to Drammeh (2024), the development of tourism and consumer preferences is also a specific factor, which can change rapidly under the influence of global crises, such as the COVID-19 pandemic. Environmental regulations and market liberalization are other important determinants that fundamentally affect the management of airlines and are reflected in the value of their shares (Penela et al., 2023).

Airline stock prediction is therefore considered one of the key challenges of current research. Its results are important not only for investors, who can use them to better manage risks and diversify portfolios, but also for airlines themselves. The development of stocks reflects not only their current financial results, but also investor confidence, which affects the ability of companies to raise capital for modernization and expansion (Thorbecke, 2020).

In recent years, there has been an increasing number of studies focusing on the application of artificial intelligence methods in stock prediction, both in stock markets in general and in the transport and aviation sectors specifically (Sonkavde et al., 2023). These works confirm that airline stock prediction is becoming an increasingly important topic of academic and practical interest. An example is the study by Xu et al. (2023), which focused on the prediction of daily closing prices of three major Chinese airlines. The authors used a combination of LASSO to select relevant predictors and external variables from the macroeconomic and aviation sectors. The results showed that this approach provides more stable and accurate forecasts than traditional models and emphasizes the importance of combining technical and fundamental indicators. Zheng et al. (2021) focused on the aerospace sector, including manufacturers and operators, and tested a hybrid model combining principal component analysis (PCA) with a recurrent neural network (RNN). Their results confirmed that appropriate data pre-treatment using PCA increases prediction accuracy and improves computational efficiency, while it was shown that specific company characteristics affect the optimal model settings. Another contribution to this area was made by Choi and Choi (2023), who focused on American Airlines shares. Their LSTM model was enriched with information from the oil market, since the price of fuel is one of the key cost factors for airlines. The study confirmed that including oil price determinants in the prediction significantly improves the accuracy of the results and better reflects the sensitivity of airline stocks to fuel-related costs. Deb (2021) focused on the public sentiment factor, examining the short-term volatility of the stocks of three US airlines - American Airlines, Delta Airlines and United Airlines. He included signals from Twitter and Google Trends in modified GARCH models, testing the effect of "internet attention" on stock performance. The findings showed that incorporating this data significantly improves the models' ability to predict short-term fluctuations and confirms that investor behavior is increasingly shaped by the online environment.

3. Research objective and methodology

Deutsche Lufthansa Group, also known as Lufthansa Airlines, headquartered in Cologne, was established in 1953. It is Germany´s largest airline and one of the leading carriers in Europe. The main hubs are Frankfurt and Munich airports. Lufthansa AG is the core entity within the Deutsche Lufthansa Group (LHAG), which also encompasses SWISS, Austrian Airlines, Brussels Airlines, and Eurowings. LHAG provides air transport services to over 200 destinations worldwide and is a co-founder of the Star Alliance. The company is structured into two primary segments: "Passenger Airlines" and "Airline Services", the latter of which includes logistics and technological operations (Lufthansa Group, 2025).

3.1 Data

Historical stock price data used for the time series analysis and predicting stock price of Deutsche Lufthansa Group (LHAG) were obtained from the financial markets' platform Investing.com (Investing.com, 2025). The dataset covers the period from 2 January 2004 to 31 December 2024 and includes only trading days (i.e.,

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2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/e7888298227

excluding weekends and public holidays). Since LHAG shares are not traded individually, data relating to the entire group, available on the German stock exchange BATS Europe (now known as "Cboe Europe Equities"), will be used for the period from 25 November 2008 to 31 December 2024. The data will be downloaded in .csv format and subsequently processed in Microsoft Excel to prepare them for analysis.

The data will be divided into seven columns, specifically date, closing price, opening price, daily high, daily low, trading volume, and daily change. This procedure will be performed for the entire selected period and the related data will be modified to ensure the compatibility with the requirements of the subsequent analysis. For the characterization of Lufthansa and the relevant historical events, supplementary data from CAPA Centre for Aviation, the Statista platform, and the Lufthansa Group's official website sources will be drawn. Furthermore, data from economic and statistical sources such as Google Finance, Sustainalytics, and the company´s annual report for the fiscal year 2023 will be used.

3.2 Methods

To answer RQ1, graphical analysis, document analysis, and time series analysis will be used based on a review of available sources. Historical events and related documents that have influenced the impact on the share price and its subsequent market development will be examined.

To answer RQ2, a time series analysis and prediction of the development of Deutsche Lufthansa Group´s share price will be carried out. For this purpose, a neural network model will be applied using Statistica (Data Science Workbench, version 14) by TIBCO Software Inc. First, it is necessary to preprocess the data into a format compatible with the neural network requirements. The analysis will use daily closing prices of Deutsche Lufthansa Group shares. After the import of data into the software, necessary values for descriptive statistics will be calculated, including mean, median, modus, standard deviation, variance, skew, kurtosis, as well as minimum and maximum values, etc.

The regression using neural network method will be applied. The output of its application is the creation of two neural network models, specifically a Radial Basis Function (RBF) and a Multilayer Perceptron (MLP) network. The dataset used for the neural network calculations will consist of 14,672 input values. The dependent variable will be the closing stock prices of individual airlines, while the independent variable will be time. Figures 1 and 2 provide a graphical representation of the RBF and MLP neural network models.

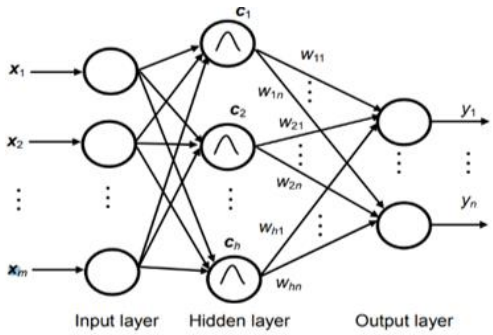


Figure 1. Radial Basis Function (RBF)

The Radial Basis Function (RBF) has the following mathematical expression:

$$y(\vec{x}) = e - (\frac{\| \vec{x} - \vec{c} \|}{b} \quad (1)$$

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/e7888298227

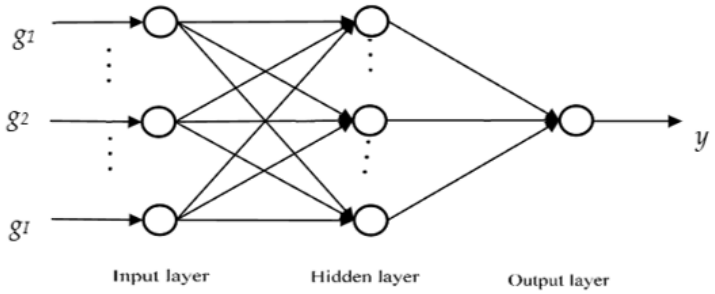


Figure 2. Multilayer Perceptron (MLP) network

The mathematical expression of the Multilayer Perceptron (MLP) networks is as follows:

$$y(\vec{x}) = \sigma(\sum_{i=0}^{n} w_i x_i) \tag{2}$$

Time series will then be randomly divided into three categories, specifically training, testing, and validation. The training category will serve as a foundation for creating the neural network structures and will thus contain 80% of the input data. The testing category is used to validate the resulting reliability of the trained neural network, while the validation category will monitor ongoing reliability and performance during the training process. These categories will thus contain 10% of the input data each. For each company, a total of 1,000 neural networks will be generated. From these, the 10 most successful neural networks with the best characteristics and suitable for predicting future company performance will be selected using an error function based on the least squares method. The mathematical expression of the least squares method is as follows:

$$E_{sos} = \frac{1}{2N}\sum_{i=1}^{N}(y_i - t_i)^2 \tag{3}$$

The hidden layers of the multilayer perceptron (MLP) neural network for Deutsche Lufthansa Group will contain at least 2 and a maximum of 25 neurons. Similarly, the hidden layers of the radial basis function (RBF) network will also contain between 2 and 25 neurons. The activation functions used in the training algorithm for both the hidden and output layers of the MLP network will include sine, exponential, hyperbolic tangent, logistic, and linear (also referred to as the identity or linear sigmoid function). All other software settings will remain default, with automatic network creation (ANS) enabled. Table 1 presents the mathematical formulas of the respective activation functions.

Table 1. Activation function and their mathematical representation

Function	Definition	Interval
Sine	$\sin(a)$	$[0; 1]$
Exponential	e^{-a}	$(0; +\infty)$
Hyperbolic tangent	$\frac{e^{a} - e^{-a}}{e^{a} + e^{-a}}$	$(-1; +1)$
Logistics	$\frac{1}{1 + e^{-a}}$	$(0\ ; 1)$
Identical sigmoid	a	$(-\infty; +\infty)$

Source: Author according to Šuleř and Machová (2019)

The BFGS (Broyden–Fletcher–Goldfarb–Shanno) optimization algorithm will be used to adapt the machine learning model. The final step of the process will be validation, which involves measuring the difference

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/e7888298227

between the stock price predictions generated by the neural networks and the actual stock prices of each airline. The result of this validation will be the residuals, representing the discrepancies between predicted and observed values.

4. Results

This chapter presents the results and findings obtained through the application of the aforementioned methods, using tables and figures where appropriate. The first and second subchapters outline the general characteristics of the Deutsche Lufthansa Group, and the historical development of the closing stock prices for the period 2008–2024. The third subchapter provides descriptive statistics. The final section outlines the anticipated future development of the closing stock prices of the Deutsche Lufthansa Group.

4.1 General characteristics of the company

From an economic perspective, the Deutsche Lufthansa Group reported total assets of EUR 45.32 billion and total liabilities of EUR 35.61 billion at the end of the fiscal year 2023 (1 January 2023 to 31 December 2023). Net income amounted to EUR 1,7 billion, with a net profit margin of 7.6%. Earnings before interest, taxes, depreciation, and amortization (EBITDA) reached EUR 3.94 billion, operating cost totalled EUR 5.35 billion, and free cash flow (FCF) stood at EUR 1.846 billion. However, the return on assets (ROA) was only 2.93%, while the return on capital (ROC) reached 13.1%. At the end of the fiscal year 2023, a total of 1.20 billion shares were outstanding, and earnings per share (EPS) amounted to EUR 1-39. According to Google finance (2024) and Lufthansa Group (2025), the company operated a fleet of 321 aircraft by the end of 2024, primarily comprising models such as Airbus A319, A320, A321, A330, A340, A350, A380, A320NEO, A321NEO, as well as Boeing 747, 787, CRJ-900 Lufthansa Group (2025). Currently, the increasingly cited topic of sustainability and corporate responsibility is also being addressed in the aviation industry. In 2024, the Lufthansa Group received an ESG score of 26.0 (rated A−), indicating medium risk (Sustainalytics, 2024). During 2023, the Lufthansa Group operated 14% more flights compared to 2022, totalling approximately 946,000 flights, with an average passenger load factor of 83%. Nearly 122.5 million passengers were carried during the year, a result also attributed to the contribution of highly qualified employees. By the end of 2023, the Lufthansa Group employed nearly 100,000 staff members (Lufthansa Group, 2025).

4.2 Historical events in airline industry

Throughout its history, Deutsche Lufthansa Group has undergone significant transformations, mainly driven by external factors. They have inevitably influenced the volatility of its stock prices. In the years 2007–2008, Lufthansa Group performed very well, establishing a stable revenue base through strategic investment in fleet expansion, penetration of the Asian market, and diversification into technical services (Lufthansa Technik) and in-flight catering (LSG Sky Chefs).

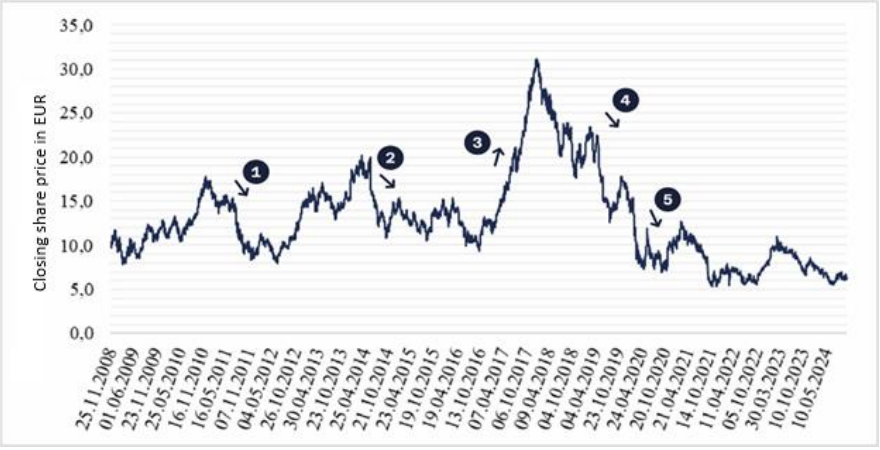


Figure 3. Historical events influencing the price trend of Deutsche Lufthansa Group shares (2008–2024)

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2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/e7888298227

In 2008, Lufthansa acquired a 45% share in Brussels Airlines for EUR 65 million, with an option to purchase the remaining 55% by 2011. This strategic move boosted the company´s share price (dw.com, 2008). At the end of 2008, however, the Global financial crisis hit the industry, leading to the implementation of stabilization mechanisms. In 2009, Lufthansa bought Austrian Airlines, which had been long struggling with financial losses, and took over 100% share in Brussels Airlines. The European debt crisis in 2009 led to a 4.5% decline in GDP, contributing to a decrease in air traffic and drop in the share price.

In 2010, operational costs increased as a result of political unrest in the Middle East and North Africa, which negatively affected the airline industry and drove up oil prices. The escalation of the European debt crisis in 2011 further impacted investor confidence, leading to a decline in Lufthansa's market value. In 2012, Lufthansa divested its unprofitable BMI subsidiary, signalling a shift in corporate strategy.

In 2014–2015, government strikes significantly affected the level of Lufthansa´s operating costs and profits due to the cancellation of thousands of flights. In 2015, the tragic crash of Germanwings 9525 caused further decline in public confidence and led to a decrease in share prices. In response, Lufthansa implemented a two-person cockpit rule and further invested in enhanced safety technologies.

In 2017, Lufthansa acquired parts of the bankrupt Air Berlin, enabling further expansion and helping the Group achieve the highest passenger traffic in its history (Lufthansa Group, 2018). However, in 2018, the company reported losses attributed to frequent flight delays and rising fuel prices, both of which contributed to another decrease in share prices.

In 2019, Lufthansa faced increasing competition from low-cost carriers and growing pressure to reduce CO2 emissions. However, the company maintained solid performance due to the partial sale of its LSG Group division (Lufthansa Group, 2018). At the beginning of 2020, the demand for global air travel was disrupted significantly by the COVID-19 pandemic, resulting in an 80% decline in revenue. Lufthansa accepted a bailout package from the German government, amounting to EUR 9 billion, which enabled the company to navigate this challenged period (Lufthansa Group, 2018).

The Russia-Ukraine war conflict in 2022 caused another decline in the demand, while the closure of Russian airspace significantly affected several travel routes (Lufthansa Group, 2025). In 2023, Lufthansa sold the remaining share of LSG division and continued to invest in profitability and fleet modernization.

In 2024, Lufthansa faced challenges including inflation, high fuel prices, employee strikes, and ongoing investments in modernization. Despite these challenges, the company started a comprehensive recovery program aimed at strengthening its long-term market position (Lufthansa Group, 2025). In 2025, Lufthansa´s share price is expected to rise, supported by the anticipated integration of the Italian airline ITA Airways into the group.

4.3 Descriptive statistics

This chapter presents the basic statistical characteristics of the input data used for the application of a neural network method. The descriptive statistics are provided in the graphical form in Figure 4.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/e7888298227

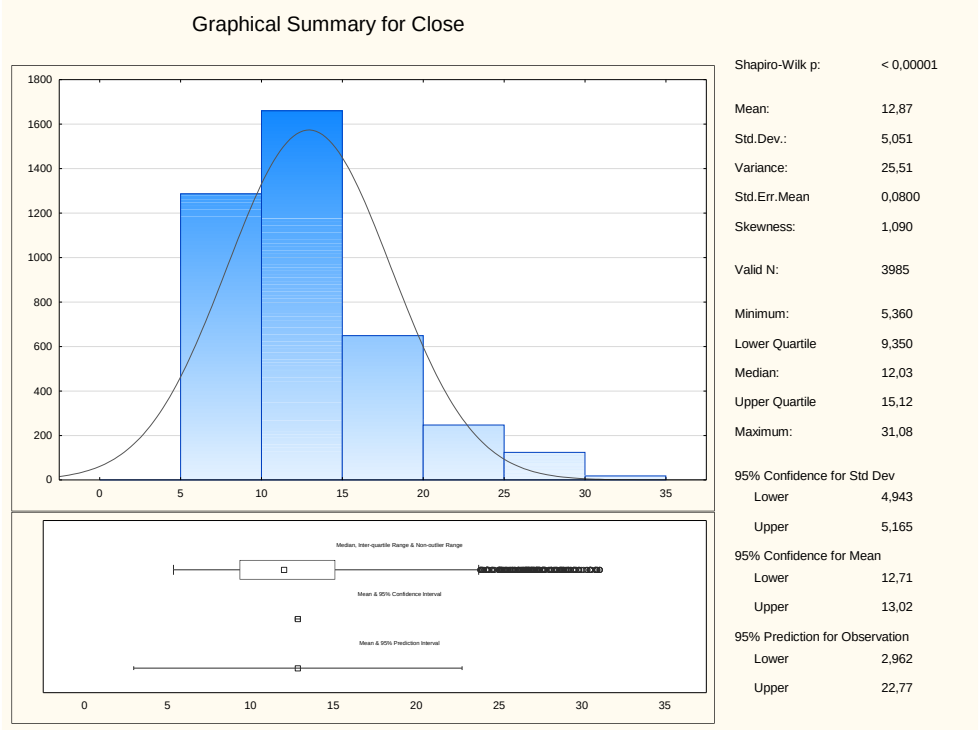


Figure 4. Basic statistical characteristics of share price trend (LHAG, 2008–2024)

The histogram illustrates the trend in stock prices by distributing the data into intervals. The red curve in the histogram represents the Gaussian (normal) distribution curve. The highest point of this curve corresponds to the mode, which denotes the most frequently occurring value in the dataset. The curve highlights the difference between the empirical distribution and the theoretical distribution of the data. In the case of a perfectly normal distribution, the blue bars would align closely with the red curve; however, this alignment is not observed here due to several deviations in the actual data distribution.

This deviation is further confirmed by the result of the Shapiro–Wilk test of normality (displayed in the top right corner of the figure), where the p-value of < 0.00001 clearly indicates a significant departure from a normal distribution. Beneath the Shapiro–Wilk test result, the descriptive statistics are presented, with the exception of the lower quartile (EUR 9.145) and the upper quartile (EUR 15.43). Below the histogram, a box plot displays the median, interquartile range, potential outliers, confidence intervals, and prediction intervals.

The confidence interval for the standard deviation ranges from EUR 4.943 to EUR 5.165, indicating consistency in the measure of variability. The confidence interval for the median spans from EUR 12.71 to EUR 13.02, suggesting a high level of precision in the estimation of the central value. Lastly, the prediction interval for individual observations ranges from EUR 2.962 to EUR 22.77, reflecting a relatively wide spread and indicating a high degree of price volatility in the stock of the Deutsche Lufthansa Group during the observed period, i.e., from 2008 to 2024.

4.4 Results of artificial neural networks

Table 2 shows the overview of these 10 retained active multilayer perceptron (MLP) network.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/e7888298227

Table 2. Overview of retained active neural networks (LHAG, 2008–2024)

Index	Net. name	Training perf.	Test perf.	Validation perf.	Training error	Test error	Validation error	Training algorithm	Error function	Hidden activation	Output activation
1	MLP 1-25-1	0.966973	0.972620	0.964269	0.824041	0.695220	0.922786	BFGS 532	SOS	Tanh	Identity
2	MLP 1-17-1	0.971841	0.978954	0.968999	0.709379	0.540141	0.810222	BFGS 610	SOS	Tanh	Exponential
3	MLP 1-21-1	0.966684	0.970638	0.965497	0.831236	0.744954	0.892612	BFGS 2516	SOS	Logistic	Tanh
4	MLP 1-20-1	0.970775	0.975626	0.971029	0.730699	0.620312	0.752157	BFGS 543	SOS	Tanh	Logistic
5	MLP 1-19-1	0.964500	0.971387	0.963941	0.885894	0.729251	0.931940	BFGS 469	SOS	Tanh	Logistic
6	MLP 1-18-1	0.969092	0.973980	0.966074	0.772227	0.664128	0.877367	BFGS 288	SOS	Tanh	Logistic
7	MLP 1-15-1	0.965880	0.972462	0.964894	0.850829	0.701534	0.906798	BFGS 315	SOS	Tanh	Logistic
8	MLP 1-19-1	0.967008	0.972673	0.965579	0.823165	0.694761	0.889680	BFGS 416	SOS	Tanh	Identity
9	MLP 1-21-1	0.969316	0.973265	0.970117	0.767028	0.679674	0.774082	BFGS 612	SOS	Tanh	Tanh
10	MLP 1-18-1	0.967407	0.972007	0.965002	0.813520	0.710406	0.904582	BFGS 390	SOS	Tanh	Identity

The input layer consists of a single variable, namely the date. The hidden layer contains between 2 and 25 neurons. The output layer also contains a single neuron, representing the closing price of shares. All networks were trained using an optimization algorithm, with the sum of squares (SOS) employed as the error function. Individual retained neural network differ in terms of the activation function applied in both the hidden and output layers. The hidden layer predominantly utilizes the hyperbolic tangent (tanh) activation, and logistic function in one case. For the output layer, 4 different activation functions are used, specifically identity, exponential, hyperbolic tangent, and logistic function. The column presenting the training, testing, and validation performance contains highly important values. The research goal is to identify a network that ideally shows equal performance across all data categories (training, testing, validation) and the lowest possible error. In each category, performance is expressed using the correlation coefficient. The closer the value to 1, the more accurate the networks´ predictions are. The neural networks demonstrate very good performance in all three categories, with values ranging from 0.964500 to 0.971841 in the training dataset, from 0.970638 to 0.978954 in the testing dataset, and from 0.963941 to 0.971029 in the validation dataset. There can thus be observed a strong similarity between the individual datasets, which indicates the predictive accuracy of the neural networks. Table 3 provides a detailed overview of the networks´ predictive performance statistics in these datasets.

Table 3. Predictive performance statistics of smoothed time series (LHAG, 2008–2024)

Statistics	1.MLP 1-25-1	2.MLP 1-17-1	3.MLP 1-21-1	4.MLP 1-20-1	5.MLP 1-19-1	6.MLP 1-18-1	7.MLP 1-15-1	8.MLP 1-19-1	9.MLP 1-21-1	10.MLP 1-18-1
Minimum prediction (Train)	5.72383	5.37125	4.98089	5.85063	5.55476	5.84385	5.55959	5.74023	4.98524	5.72852
Maximum prediction (Train)	29.08998	29.61810	28.46726	28.48416	27.96875	29.43971	28.07520	29.01453	27.20204	28.86259
Minimum prediction (Test)	5.73585	5.37129	5.07686	5.86763	5.55509	5.84396	5.56520	5.75503	5.07541	5.72832
Maximum prediction (Test)	29.08879	29.57839	28.46681	28.42711	27.96783	29.42026	28.07541	29.01552	27.17961	28.84252
Minimum predic. (Valid.)	5.72436	5.37145	5.01296	5.85077	5.55494	5.86750	5.55955	5.74008	5.01533	5.72857
Maximum predic. (Valid.)	29.02730	29.59689	28.46714	28.47024	27.96080	29.42985	28.05069	29.01263	27.19659	28.85258
Minimum residual (Train)	-3.84272	-3.64551	-4.13171	-4.34414	-4.04813	-3.81815	-4.05297	-3.97776	-4.01865	-4.34243
Maximum residual (Train)	4.41957	4.27349	4.37556	3.99286	4.60042	4.18766	4.59903	4.54461	4.21195	4.38136
Minimum residual (Test)	-2.94660	-2.97540	-3.27082	-3.46885	-3.64287	-3.10277	-3.28550	-2.99464	-3.51444	-2.99962
Maximum residual (Test)	4.19749	4.04609	4.16140	3.77832	4.28850	4.16355	4.38672	4.32639	4.05636	4.16206
Minimum residual (Valid.)	-3.32268	-2.94451	-3.48587	-3.70318	-3.35760	-3.27998	-3.35134	-3.28528	-3.86569	-3.67298
Maximum residual (Valid.)	4.43286	4.29474	4.37698	3.99497	4.48670	4.04098	4.59753	4.55202	3.94275	4.39050
Minimum standard residual (Train)	-4.23316	-4.32832	-4.53176	-5.08200	-4.30094	-4.34491	-4.39392	-4.38424	-4.58854	-4.81447
Maximum standard residual (Train)	4.86862	5.07392	4.79923	4.67105	4.88773	4.76540	4.98592	5.00903	4.80925	4.85763
Minimum standard residual (Test)	-3.53395	-4.04848	-3.78958	-4.40434	-4.26585	-3.80735	-3.92263	-3.59274	-4.26291	-3.55888
Maximum standard residual (Test)	5.03418	5.50531	4.82141	4.79726	5.02189	5.10903	5.23740	5.19048	4.92025	4.93805
Minimum standard residual (Valid.)	-3.45890	-3.27123	-3.68960	-4.26993	-3.47805	-3.50171	-3.51936	-3.48301	-4.39374	-3.86184
Maximum standard residual (Valid.)	4.61460	4.77128	4.63280	4.60638	4.64765	4.31416	4.82802	4.82600	4.48132	4.61625

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/e7888298227

Thus, Table 3 provides information on the range and accuracy of the predicted values. It also includes the residual values. Ideally, these should be equal to 0, which would indicate perfect agreement between the input data and the resulting predictions. However, the table shows that although the residuals are often close to 0, there are slight deviations, indicating a certain level of inaccuracy in the neural network's predictions. Despite these deviations, the networks perform successfully and are considered capable of predicting closing stock prices with high reliability. This is further illustrated in detail in Figure 5.

The data are divided into training, testing, and validation datasets. The first part of the table presents the results for the minimum and maximum predicted values. For example, the first row of the table shows the minimum predicted values for the training set, ranging from 4.98 to 5.80, while the second row shows the maximum values, ranging from 27.20 to 29.63. Similarly, the table presents the minimum and maximum predicted values for the testing and validation sets. The second part of the table displays the minimum and maximum residuals for the training, testing, and validation datasets in the same way. The final part of the table presents the standardized residuals for each dataset, i.e., normalized deviations between the predicted and actual values using the standard deviation. This standardization helps to detect outliers, which indicate the inaccuracy of individual MLP networks in their predictions.

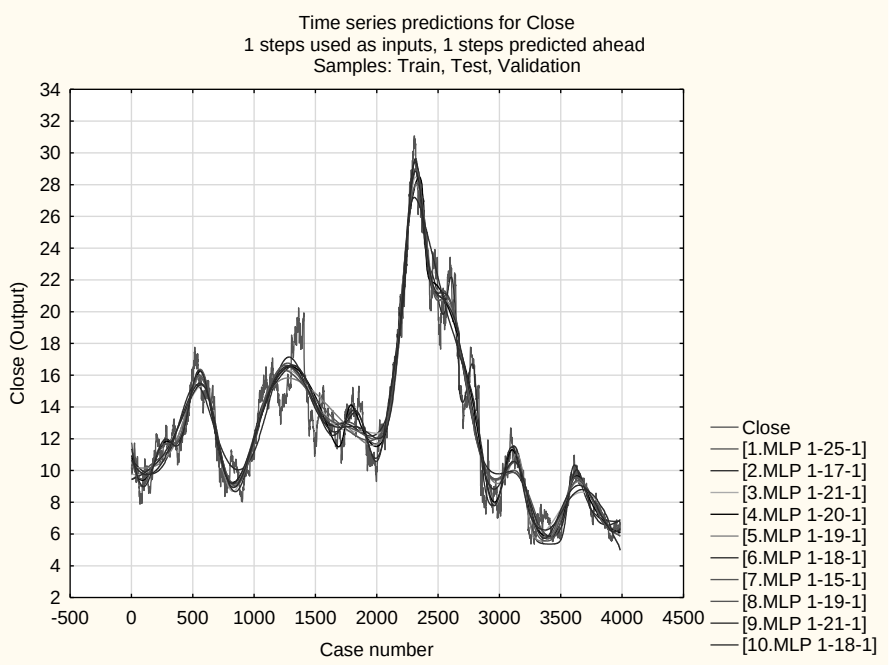


Figure 5. Share price trend predicted using neural networks (LHAG, 2008–2024)

Figure 5 shows the smoothed time series of historical closing share prices in the monitored period 2008–2024. The blue curve represents the actual development of share prices, while the other differently coloured curves depict the development of prices as predicted by the ten retained MLP networks. It should be emphasized that this is not a forecast of future prices, but rather a record of how well each network was able to reconstruct the known historical values in comparison with the actual data. The resulting residuals are shown in more detail in Figure 6. As illustrated in the graph, the retained networks performed very well and were able to replicate the actual stock price development with a high degree of accuracy. Although some deviations can be observed at local maxima and minima between the actual and predicted values of individual networks, these discrepancies should not significantly affect the overall reliability of the prediction. The historical development of stock prices over the years demonstrates considerable volatility. The share price reached its peaks in the years 2010 (value 500), 2014 (value 1,500), and 2017 (value 2,400), while notable troughs occurred in more recent years, specifically in 2021 (value 3,250) and 2024 (value 4,000).

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
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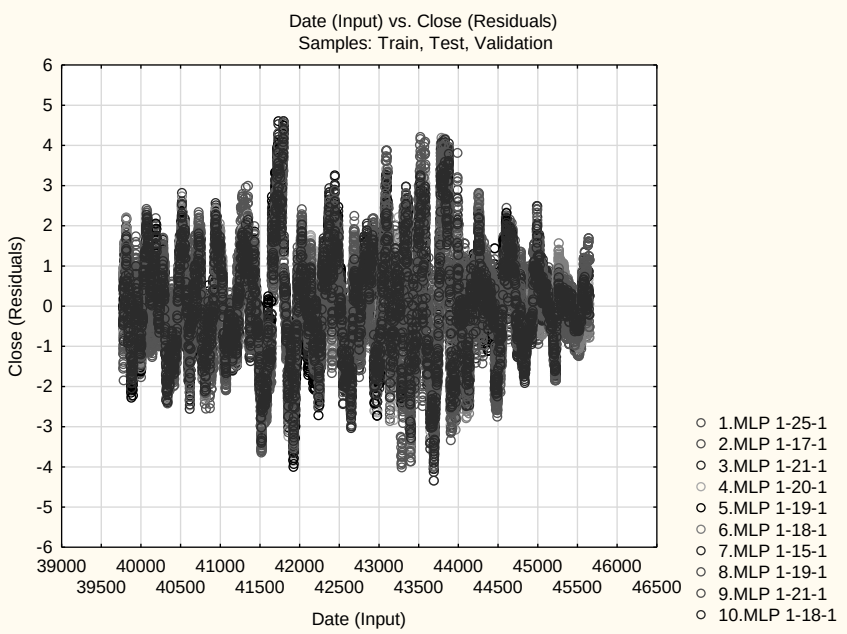


Figure 6. Graph of historical data residuals (LHAG, 2008–2024)

Figure 6 displays the residuals between the actual share price and the values predicted by the 10 retained neural networks. The horizontal (x) axis represents the date, while the vertical (y) axis shows the residual values. Ideally, the values of individual residuals should be as close to zero as possible, indicating minimal deviation between predicted and actual prices. However, the neural networks do not achieve perfect accuracy in some cases. This is evident from values that deviate either positively or negatively from zero. The largest residual deviations are observed particularly between the years 2013 and 2014 (values ranging from 41,500 to 42,000) and during the period from 2017 to 2020 (values between 43,000 and 44,000). In these intervals, the residuals vary within the range of approximately -4 to 5 and -4 to. During the rest of the monitored period, the values are concentrated around the desired value of zero, mostly within the -2 to 2 range, which indicates very good prediction accuracy. The performance of individual MLP networks could be seen in Figure 7.

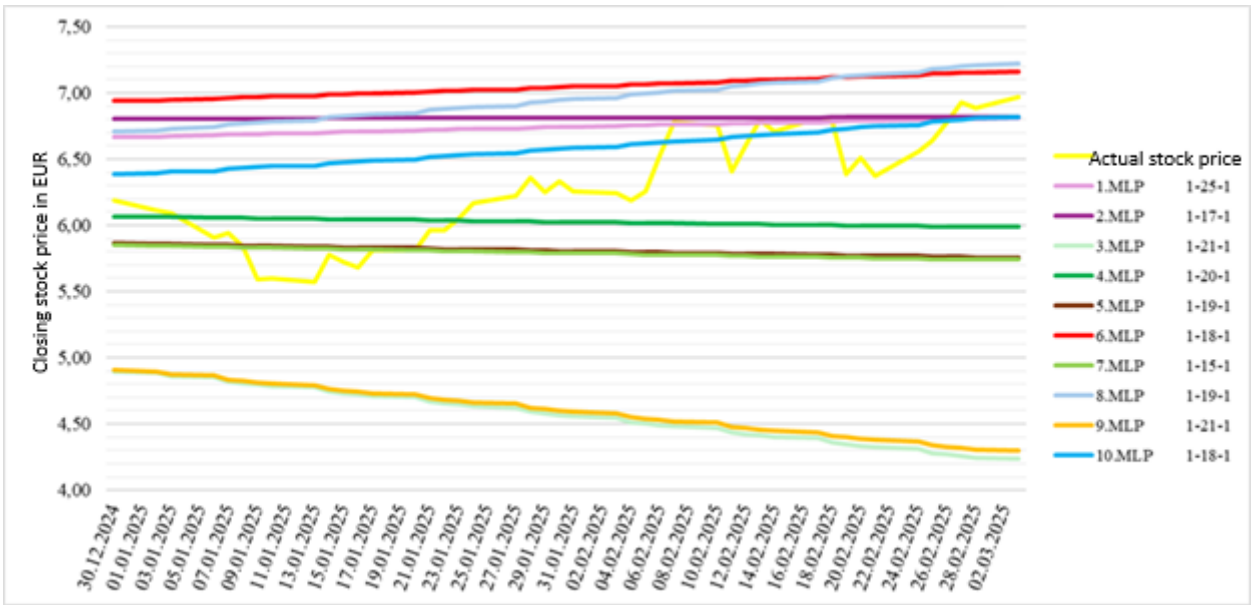


Figure 7. Predicted closing price of Lufthansa Group´s stock by MLP networks

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2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/e7888298227

Figure 7 illustrates the short-term forecast of the closing share price of the Lufthansa Group airline, covering the period from 30 December 2024 to 3 March 2025. As seen in the graph, the yellow curve represents the actual closing price of LHAG shares as recorded on the German stock exchange (Cboe Europe Equities) during the observed period. The remaining differently coloured curves display the predicted values over the same period, as generated by the 10 retained MLP networks. The actual share price ranged between EUR 5.50 and 6.50 from 30 December 2024 until 6 February 2025, when it first exceeded the upper bound of this interval. From that point onward, the price followed an upward trend—with minor fluctuations—reaching its peak of EUR 6.97 on 3 March 2025. Conversely, the lowest recorded value during the analysed period was EUR 5.57, observed on 13 January 2025. As can be seen from the figure, the actual development of the closing share price of Lufthansa Group did not exhibit any significant volatility over the monitored timeframe.

The figure shows that the orange and peppermint curves corresponding to 3.MLP and 9.MLP networks exhibit a markedly decreasing trend and a trajectory that significantly diverges from the actual development of the share price. As such, these networks appear to be the least accurate. Only the brown and light green curves, representing the 5.MLP and 7.MLP networks, indicate a slightly declining trend, whereas the remaining networks generally follow an upward trajectory. In contrast, the purple, red, and light blue curves (2.MLP, 6.MLP, and 8.MLP networks) approximate the accurate trend of the share price. However, they predict excessively high share prices ranging from EUR 6.67–7.22, which constitutes a notable deviation from the actual closing prices. As seen in the graph, the dark blue curve (10.MLP network) best captures the closing price, accurately reflecting both the trend and direction of the actual share price. The pink and dark green curves (1.MLP and 4.MLP networks) also performed well, displaying only minor deviations from the actual price trend. The three most accurate MLP networks are displayed in detail in Figure 8.

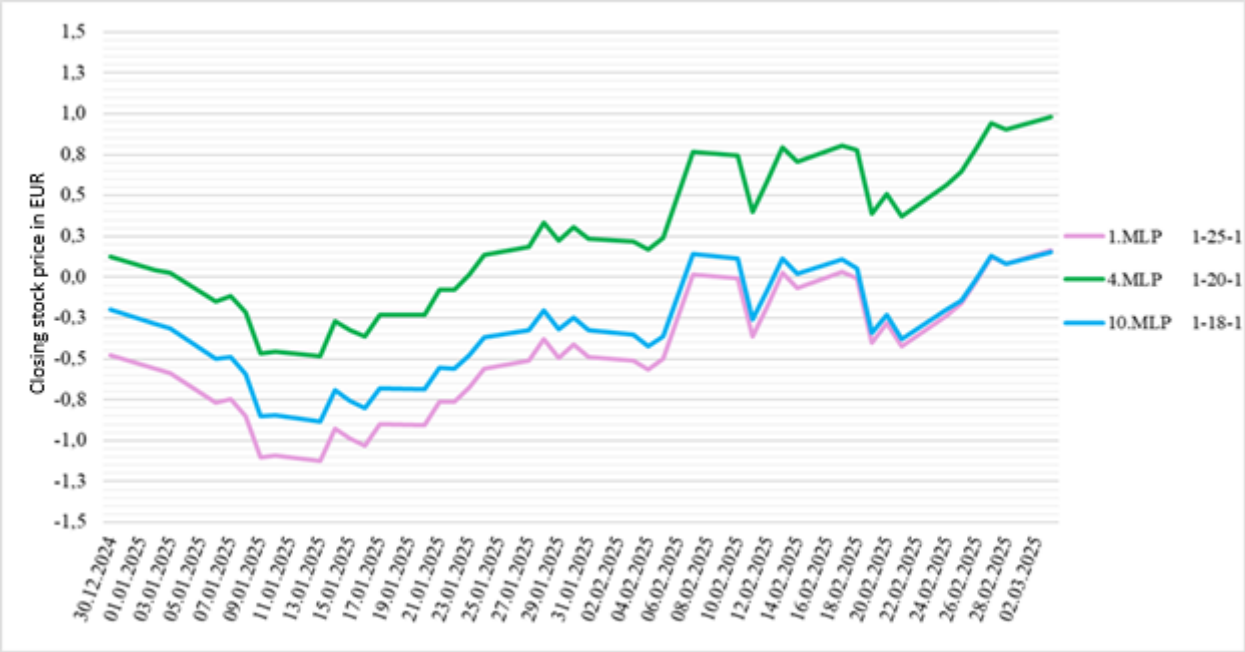


Figure 8. Residual graph of the closing share price prediction for Lufthansa Group by MLP networks

Figure 8 presents the three most accurate neural networks predicting the share prices of the Lufthansa Group. The most suitable MLP network is the one with the average residual closest to zero, which indicates a perfect match with the actual share price. The most accurate model is MLP network No. 10, which demonstrates an average residual value of 0.3579, representing a highly satisfactory result. The smallest residuals observed for this network are -0.011, 0.019, and 0.057, while the largest residuals reach -0.881, -0.849, and -0.845. The median residual is 0.3210. This network thus provides the most stable prediction with the smallest deviations from the actual price and is considered the most suitable for predicting the closing share price of the Lufthansa Group. The second most accurate network is MLP network No. 4, which yields an average residual of 0.4070. The smallest residuals for this model are 0.015, 0.027, and 0.044, while the largest reach 0.983, 0.940, and

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2025 Volume 13 Number 2 (December)
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0.902. The third most accurate model is MLP network No. 1, with an average residual of 0.4884. It shows extremely small residuals of -0.005, -0.006, and 0.017, which are very close to zero. However, its largest residuals exceed the value of -1, specifically -1.126, -1.101, and -1.094, indicating a relatively significant divergence. It is evident that residuals can be both positive and negative, as they merely represent the difference between the predicted and actual values – i.e., the distance from zero. The graph also shows that all three top-performing networks exhibit an initial downward trend followed by an upward trend, which mirrors the actual share price movement. An interesting observation is that the largest residuals for all three MLP networks occur on consecutive trading days.

5. Discussion

The aviation industry is a dynamic sector that must be able to adapt to rapid changes in the needs of modern society. With the growing popularity of air travel, expectations regarding service quality, comfort, and reliability are increasing. Due to geopolitical crises, technological advancements, and globalization, airlines are under pressure, and their management must effectively respond to changes and challenges in the macroeconomic environment while simultaneously modernizing services, fleet, and staff training. These transformations affect both air carriers and the development of their share prices.

Based on the results obtained from graphical analysis, document analysis, time series analysis, and artificial neural networks, it is possible to answer the formulated research questions.

To address RQ1, which examines the factors influencing the volatility of Deutsche Lufthansa Group´s share price, historical data were analysed along with the identification of the key factors that had the greatest impact on the development of share prices in the period 2004–2024. The most significant influences include external shocks, such as the COVID-19 pandemic, which led to a considerable decline in the demand for air transport and a subsequent drop in Lufthansa´s share prices in 2020–2022. However, this decline was mitigated by Lufthansa´s rapid response to the crisis and utilization of government bailout, while some of its competitors were more severely affected.

Another significant external factor was the 2008 global financial crisis and its consequences, including the European debt crisis, which led to an increase in operating costs, a decline in demand, and a general deterioration of the economic environment, subsequently influencing the volatility of Lufthansa´s share prices. The rising fuel prices in the years 2011–2012 and 2018 also contributed to increased volatility in Lufthansa´s stock performance; however, fuel hedging contracts helped mitigate fluctuations in the case of low-cost carriers.

Internal factors influencing the volatility of share prices include employee strikes, particularly the major actions in the years 2014–2015 and again in 2024, which directly affected operational costs and investor confidence. The implementation of a new corporate strategy also had an impact on the volatility of Lufthansa´s share price. The significance of these factors is supported by studies such as Vochozka et al. (2022), which demonstrate that share price movements are influenced not only by macroeconomic variables, but also by internal factors such as corporate strategy, organizational restructuring, or acquisitions.

To address the R2, a prediction method based on multilayer perceptron neural networks was used to forecast the development of share prices of Deutsche Lufthansa Group for January and February 2025. The network with the lowest average residuals from actual values was selected, indicating minimal deviations between predicted and observed data. The results indicate that the expected development of Lufthansa's share price is likely to follow a slightly upward and stable trend. The forecast begins at EUR 6.39 and rises to EUR 6.82 by the end of February, suggesting positive expectations and cost stabilisation.

Based on these findings, it can be stated that the application of MLP neural networks is an effective method for forecasting the stock performance of Deutsche Lufthansa Group. However, as noted by Gite et al. (2021) and Zheng et al. (2021), prediction remains challenging in a turbulent market environment.

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2025 Volume 13 Number 2 (December)
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Conclusions

Nowadays, events that disrupt the stability of the global economy and financial markets occur with increasing frequency. Geopolitical uncertainty, pandemics, oil or fuel price fluctuations, and changes in legislation drive investors to reassess the potential of various sectors, including aviation, which is one of the most sensitive sectors. The aviation industry also offers attractive investment opportunities, which increases the demand or tools for predicting stock price and stability analysis.

The aim of the paper was to examine the development of Deutsche Lufthansa Group´s share prices, analyse the corresponding time series, and predict price trends for January and February 2025. To achieve this goal, historical daily price data for the period 2004–2024 were used to identify trends, fluctuations, and key factors influencing the volatility of share prices. The future trend was predicted using multilayer perceptron networks implemented in the Statistica software. Through graphical analysis, time series analysis, document analysis, and time series analysis, the study identified both external and internal factors affecting price development. Based on these analyses, a forecast of the expected share price trend for Deutsche Lufthansa Group was produced.

The results revealed that the prediction for Lufthansa´s share prices show a slightly upward and stable trend, beginning at EUR 6.39 and rising to EUR 6.82 by the end of February 2025. This trend reflects the positive expectation and stabilization of costs, which may indicate renewed investor confidence in the company´s long-term recovery.

The objective of the paper was successfully met. All research questions were addressed, and the desired outcomes in analysing and predicting the share price development were achieved. The research limitations included the restricted availability of historical data for Deutsche Lufthansa Group, particularly from the year 2008, which constrained the scope of the analysis. Additionally, limitations related to the short time horizon of the forecast. Further research could broaden the analysis to include a larger sample of airlines and extend the prediction period, which would allow for the consideration of long-term trends and fluctuations, enhancing the accuracy of forecasts and supporting strategic planning in the aviation industry.

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THE USE OF ARTIFICIAL INTELLIGENCE IN HUMAN RESOURCE MANAGEMENT OF ENTERPRISES *

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Abstract. The modern concept of business management involves the delineation of numerous functional areas of managerial activity, including those related to the management of the human component of production – the enterprise's personnel. Global technological and structural transformations, increasing competition, the globalization of production, and the development of international relations, cooperation, and integration make the management of this critical area increasingly complex. Under these conditions, human resource specialists in many companies have begun to actively adopt intelligent technologies that support recruiters in accomplishing tasks such as staff recruitment and placement, employee training, adaptation, and performance evaluation more efficiently and in significantly shorter timeframes. The objective of this study is to explore how artificial intelligence (AI) can be effectively integrated into HR processes and, more broadly, into workplace operations in a way that does not provoke resistance from employees but instead fosters their cooperation and trust. The research was conducted through a quantitative survey designed to capture respondents' attitudes toward the potential replacement of their job positions by AI. The sample was selected randomly, with the target group consisting of employees from various sectors. A total of 411 fully completed responses were included in the final analysis. The data were processed using the SPSS software package. The results allowed to reveal attitudes of different group of employess to AI use. Finndings can be used for formulate better tackled human resource management strategies.

Keywords: human resource management; personnel management; artificial intelligence (AI); questionnaire; employees

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JEL Classifications: J24, O33

1. Introduction

In contemporary society, artificial intelligence (AI) has increasingly emerged as a transformative tool that fundamentally reshapes the functioning of organizations across diverse sectors, including human resource management (HRM). The rapid advancement of technology and its integration into workplace environments have accelerated the adoption of AI-based applications. HR departments are progressively employing such tools to automate processes, optimize operations, and enhance the overall quality of their activities. This issue is of particular relevance, as it extends beyond the technical and organizational domains to encompass ethical considerations, employee trust, and the future of work. The integration of AI affects virtually every employee and employer, as it alters approaches to recruitment, performance evaluation, training, and the execution of routine tasks. Consequently, the study of AI in HRM carries both theoretical significance and practical implications, offering valuable insights into the broader impact of this technological transformation.

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Artificial intelligence is grounded in the premise that computers and machines can be designed to replicate human cognitive functions such as reasoning and learning. This idea dates back to the 1950s, when the first AI programs were developed. Today, AI constitutes an integral part of everyday life, serving as a powerful instrument for information retrieval, problem-solving, planning, data analysis, and other essential activities. AI embodies the capacity of a system to exhibit human-like abilities, including reasoning, learning, planning, and creativity. Through AI, technical systems are capable of perceiving their environment, identifying problems, and acting in pursuit of predefined objectives. Data are acquired either from prepared sources or collected via sensors (e.g., cameras), processed by the system, and subsequently utilized to generate responses.

AI systems are characterized by their ability to operate autonomously and to adapt their behavior based on the analysis of prior actions. This adaptability has facilitated their growing application in key sectors such as healthcare, manufacturing, and transportation. A particularly noteworthy field of application is human resource management. HRM represents a targeted activity undertaken by an organization's leadership team, together with managers and specialists within the personnel management system. It encompasses the formulation of concepts and strategies for personnel policy as well as the development of methods for managing employees. The adoption of AI technologies in HRM can significantly reduce the workload of HR professionals by automating routine tasks, thereby allowing them to focus on strategic and value-adding activities.

2. Theoretical background

Although artificial intelligence is often perceived as something new and inherently tied to the modern – primarily information-based – society, it is in fact a phenomenon that has captured the attention of thinkers and visionaries for centuries, arguably since the beginning of the First Industrial Revolution, when one of its essential features was the replacement of human labor with machines. The term *artificial intelligence* is generally used to describe systems that demonstrate intelligent behavior by analyzing their environment and taking actions with a certain degree of autonomy. In this sense, it refers to the capacity of technologies to perform tasks that are typically assumed to require human intelligence (Mugunzva & Manchidi, 2024). Artificial intelligence is rapidly transforming employers' established processes. It offers speed and efficiency, which explains its growing application in recruitment, management, and employee evaluation—areas traditionally reserved for human decision-making.

Artificial intelligence can be understood in different ways. At present, it is predominantly viewed as a scientific discipline that draws on knowledge from other fields such as mathematics, logic, statistics, and computer science. In a narrower sense, it refers to specific processes or capabilities possessed or executed by computers (in the broadest sense—PCs, tablets, robots, etc.) or their software (Vojtuš, Kordík & Dražová, 2023).

According to the OECD Council Recommendation on Artificial Intelligence, "artificial intelligence is a system capable of finding optimal or suitable recommendations, solutions, or decisions for human-defined objectives, which influence the surrounding environment in either a real or virtual manner" (OECD, 2022). In a very general characterization, artificial intelligence represents a system operating autonomously with a high capacity to solve problems defined by humans. This ability of AI to think abstractly and derive specific actions, conclusions, or decisions has fundamental practical as well as legal implications. Ultimately, control over these autonomous AI systems should remain with humans, especially in situations where such systems exercise their ability to make independent decisions (Barancová, 2024).

Artificial intelligence operates on the principle of a set of algorithms or computational formulas that program a computer system. An AI algorithm represents a sequence of precisely defined steps, instructions, or rules that enable AI to effectively solve problems, identify patterns, and adapt to new situations (Štalmachová & Strenitzerová, 2020).

Artificial intelligence is emerging as a transformative innovation with the potential to drive substantial economic growth and productivity gains (Damioli, 2025). For workers, it is essential to remain committed to the continuous improvement of their skills (Lloyd & Payne, 2019). Analyses presented in several studies (Marinas et al., 2024; Holm & Lorenz, 2022; Istudor et al., 2024; Hui, 2024; Popa, 2024) suggest that artificial intelligence

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is reshaping skill requirements, particularly in more demanding positions, and is expected to have a positive impact on the employment prospects of highly educated workers. A study from Slovakia (Valaskova et al., 2024) points to the slower adaptation to Industry 4.0, largely due to deficiencies in the education system and insufficient state support, which may limit workers' ability to adapt to ongoing changes. Consequently, adapting the educational system and enhancing digital literacy are indispensable.

New forms of work are emerging through digital platforms within the sharing economy, characterized on the one hand by increased flexibility, but on the other by a markedly reduced and limited scope of labor law paternalism. Artificial intelligence has also become a common subject of debate across numerous scientific domains, including legislation, particularly in the context of copyright law. The ability to create and perceive art has long been regarded as an exclusively human trait distinguishing us from other living beings or technologies (Démuth, 2020).

Honavar (2016) provides several descriptions of artificial intelligence: AI is the science of intelligence. As a scientific discipline, AI primarily deals with falsifiable claims, i.e., testable hypotheses concerning the structures and processes that are necessary and sufficient for intelligent behavior. AI is the study of computational models of intelligent behavior—perception, cognition, and action. AI is the science of exploring the space of possible and actual intelligent systems. AI is the practice of designing and analyzing intelligent agents. AI is a branch of engineering concerned with the mechanization of tasks presumed to require intelligence when performed by humans—for example, theorem proving, route planning, face recognition, disease diagnosis, computer design, music composition, scientific discovery, mathematical proof, chess playing, story writing, teaching physics, contract negotiation, and providing legal advice. However, sound engineering must always be grounded in a solid scientific foundation. AI is no exception (Honavar, 2016).

The primary objective of AI research is to enhance our understanding of perceptual, rational, learning, linguistic, and creative processes. Such understanding is undoubtedly valuable for the design and development of innovative tools in science, industry, and culture. Just as the invention of the internal combustion engine and the development of machines such as airplanes led to an unprecedented increase in human mobility, tools emerging from AI research are already beginning to expand human intellectual and creative capacities in ways our ancestors could only imagine. A sophisticated comprehension of the fundamental mechanisms, potential, and limitations of human—as well as other forms of—intelligence is also likely to shed light on the social, environmental, and cultural challenges of our time and contribute to the search for solutions (Honavar, 2016).

Technological progress, particularly in the field of artificial intelligence, is driving increasing automation across various industries. This trend may significantly affect employment in the future, raising concerns, especially due to the potential savings in labor costs that automation brings to companies. However, the advancement of AI also brings forth perspectives emphasizing the creation of new job opportunities. For example, AI specialists may become highly sought after as a result of widespread AI implementation, making them an indispensable part of many organizations.

The field of AI consistently demonstrates strong potential for development and application across diverse sectors. Discoveries and innovations in this area inspire enthusiasm for progress among many, yet—as with any major transformation—technological advancement also evokes a wide spectrum of emotions and opinions.

Many scholars argue that the use of AI technologies does not automatically lead to rising unemployment (Gries & Naudé, 2018; Mutascu, 2021). Rather, the transformations brought about by digitalization compel the workforce to adapt to new work environments shaped by AI technologies (Abdeldayem & Aldulaimi, 2020). Meister (2019) predicted that artificial intelligence would create more jobs than it eliminates. Although employees may perceive AI as a threat, for business management it represents a significant opportunity. Its integration into corporate processes can contribute to substantial modernization and enhanced competitiveness in the marketplace. Both employees and employers are expected to benefit from the advent of automation and AI, as these technologies will perform routine tasks previously carried out by humans. This will increase productivity, based on the positive relationship of cooperation between humans and machines (Čižo, 2025). Another group of authors focuses on the challenges and risks associated with AI in the labor market (Otoiu,

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 1 (September)
http://doi.org/10.9770/q2447759355

2022). Concerns include worker displacement in certain sectors, the deepening of economic inequality, declining demand for low-skilled labor (with older workers, the low-skilled, and certain marginalized groups identified as most vulnerable), and the growing need for highly skilled employees (Badea et al., 2024; Lazaroiu et al., 2024). At the same time, however, the use of AI may boost productivity and democratize access to knowledge and expertise (Komp-Leukkunen, 2024).

The adoption of artificial intelligence can significantly facilitate the work of HR specialists while alleviating much of their workload. One of the main responsibilities of HR professionals in companies is recruiting employees across various specializations. To achieve this, recruiters must process a wide range of tasks. The use of AI in this process can substantially ease the recruiter's work by taking over a considerable share of their responsibilities. Thanks to the unique analytical capabilities of artificial intelligence, HR departments can simultaneously collect large volumes of information on each candidate applying for a specific position. Moreover, with the support of intelligent technologies, it will be possible in the future to gather data such as performance evaluations of newly hired employees, providing recruiters with essential insights into the potential of these workers (Tappaskhamíova, Mustafaeva & Tokmakova, 2020). With continuous development, AI will be able to handle increasingly complex tasks, opening up new opportunities for its application across diverse domains. However, this progress also brings numerous challenges and highlights the need for regulation, which requires careful attention.

3. Research objective and methodology

The aim of this research is to examine how artificial intelligence (AI) can be effectively implemented into HR processes and work processes in general in a way that does not provoke resistance from employees but rather fosters their cooperation and trust. The defined problem primarily concerns the question of how AI can be applied to streamline work processes while at the same time respecting the human dimension of labor and not jeopardizing job security. This study seeks to contribute to a deeper understanding of this complex issue and provide recommendations for employers who are planning to introduce, or are already implementing, AI into their organizational processes. Addressing this topic may be beneficial for both the professional and the general public interested in modern approaches to human resource management.

The research was carried out through a quantitative survey designed to investigate respondents' attitudes toward the potential replacement of their job positions by artificial intelligence (AI). The objective was to identify differences in the level of concern between men and women and to analyze the relationship between gender and attitudes toward AI. The sampling was random, targeting employees from various sectors. Data collection was conducted anonymously via an online questionnaire. The data were processed using SPSS software.

To verify the relationship between respondents' gender and concerns about AI-driven job replacement, the Chi-square test was applied. This method belongs to the group of nonparametric statistical tests used to test hypotheses regarding frequencies or variable independence. It determines whether a significant dependence exists between observed and expected frequencies in categorical data (Neubauer, 2021). To compare the distribution of responses between men and women, the Mann–Whitney U test was used. This nonparametric test is designed to compare two independent samples and determines whether the distribution of values in the two groups differs significantly (Shier, 2004). To assess the strength and direction of the relationship between variables, Goodman–Kruskal's tau and Somers' d were employed. Goodman–Kruskal's tau is an asymmetric measure of association for categorical variables, indicating the extent to which knowledge of one variable improves the prediction of another (Goodman & Kruskal, 1979). Somers' d is a measure of association for ordinal variables, expressing the extent to which the values of a dependent variable change monotonically (increase or decrease) with changes in an independent variable (Agresti, 2010).

The research was conducted in accordance with ethical principles. Participation was voluntary and anonymous, and respondents were informed about the purpose of the study.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 1 (September)
http://doi.org/10.9770/q2447759355

4. Results and discussion

A total of 437 respondents participated in the research; however, after data quality control, it was found that some responses were incomplete or inconsistent. For this reason, only 411 fully completed records that met the criteria of completeness and usability were included in the final analysis. These respondents represented different genders, age categories, and professional sectors. Therefore, the survey initially asked respondents about these identifiers (see Table 1).

Among the respondents, women were strongly predominant, accounting for 70% of the sample. From a generational perspective, more than 70% were employees of the younger generation under the age of 27 (Generation Z), for whom modern technologies, including artificial intelligence, are more familiar, and who are able to adapt more quickly to technological progress. Only 7% of the respondents belonged to Generation X (aged 44–59), who generally find it more difficult to adapt to modern technologies.

Table 1. Structure of Respondents

	Mans		Females		Together	
	n	%	n	%	n	%
Generation Z 18 – 27 years old	72	18	222	54	294	72
Generation Y (Millennials) 28 – 43 years old	39	9	48	12	87	21
Generation X 44 – 59 years old	12	3	18	4	30	7
Together	123	30	288	70	411	100

Source: own calculation

The distribution of employees by sector shows that the largest share of respondents works in trade and services (25%), followed by healthcare (21%) and industry (19%).

The use of AI at work, however, varies significantly across sectors. Information technology is the leader in everyday AI usage—most respondents from this sector report using it daily or frequently, which is natural given the technological nature of their work. In the trade and services sector and in industry, AI is also widely employed, with many respondents indicating frequent or occasional use, particularly for process automation, data analysis, production planning, and customer support.

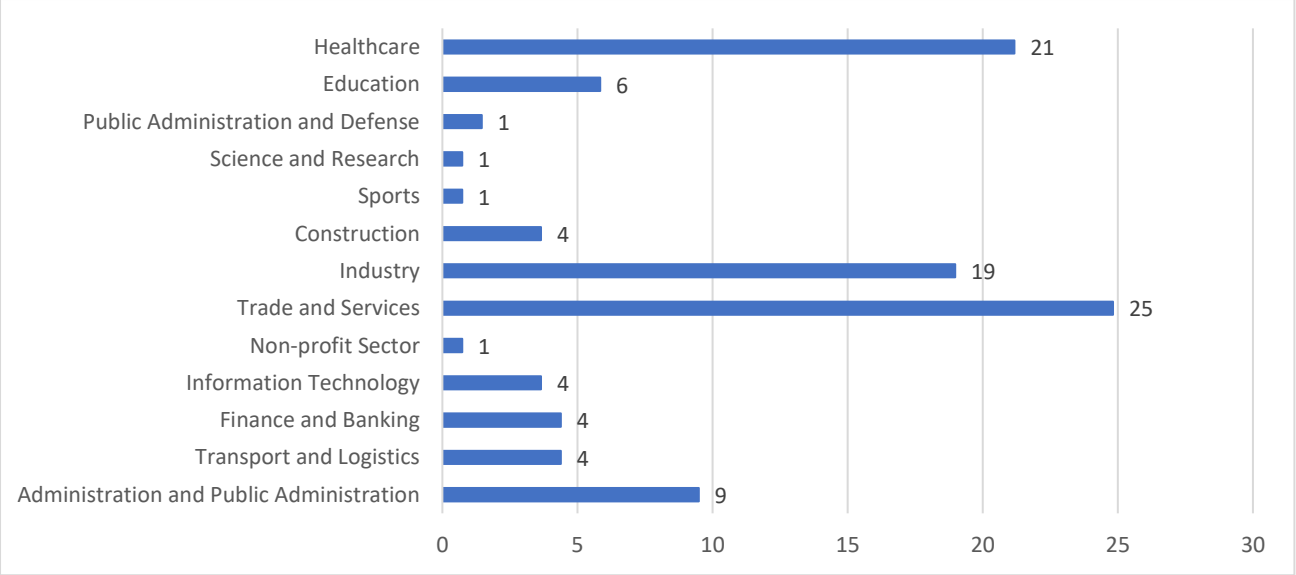


Figure 1. Respondents' Employment Sectors (%)
Source: own calculation

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 1 (September)
http://doi.org/10.9770/q2447759355

In healthcare, AI is used occasionally or rarely. It assists in diagnostics, service planning, and competence assessment, but its implementation has not yet become widespread. A similar pattern is observed in education and finance, where AI serves as a supplementary tool—for example, in personalized learning or risk analysis. Conversely, in sectors such as sports, the non-profit sector, public administration and defence, transportation and logistics, or construction, AI usage is minimal or nonexistent, with most respondents reporting that they never use it. This may be linked to lower levels of digitalization, limited resources, or a lack of awareness of AI's potential applications.

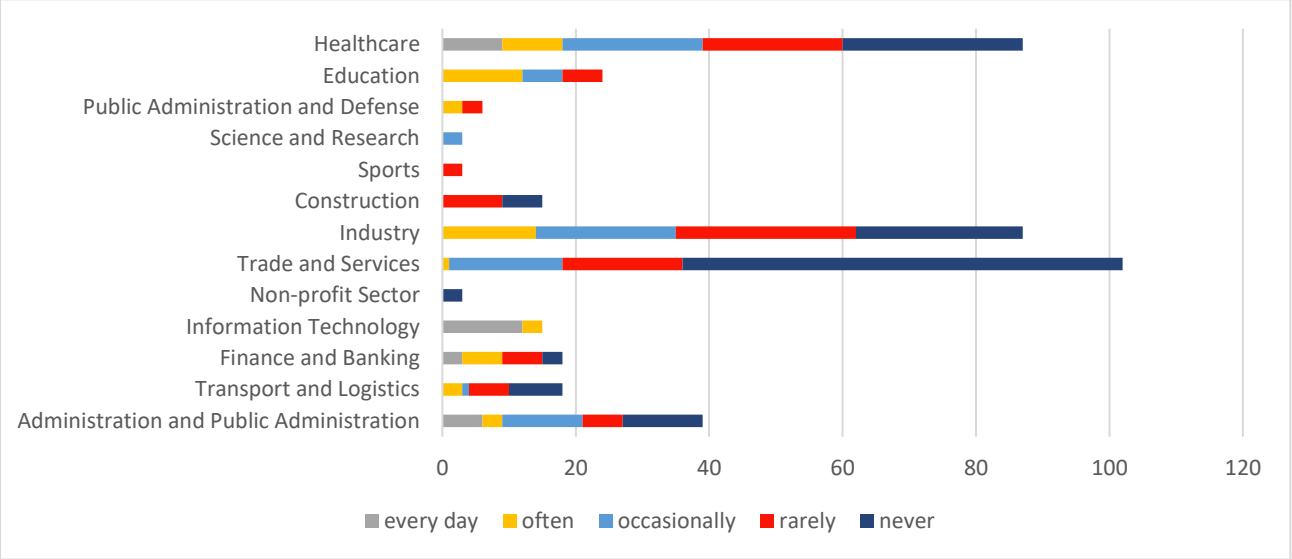


Figure 2. Use of AI in the Workplace
Source: own calculation

The survey results indicate that the majority of respondents are rather reserved toward the use of artificial intelligence in HR processes. The strongest resistance is observed in relation to AI-conducted interviews and AI-based evaluations, where more than half of the participants stated that they would not want such an approach or would find it objectionable. Specifically, 153 respondents (37%) reported that they do not wish to undergo an interview with AI, and 99 respondents (24%) indicated that they would find it bothersome. Only 18 respondents (4%) stated that such an interview would suit them and that they would explicitly prefer to participate in it.

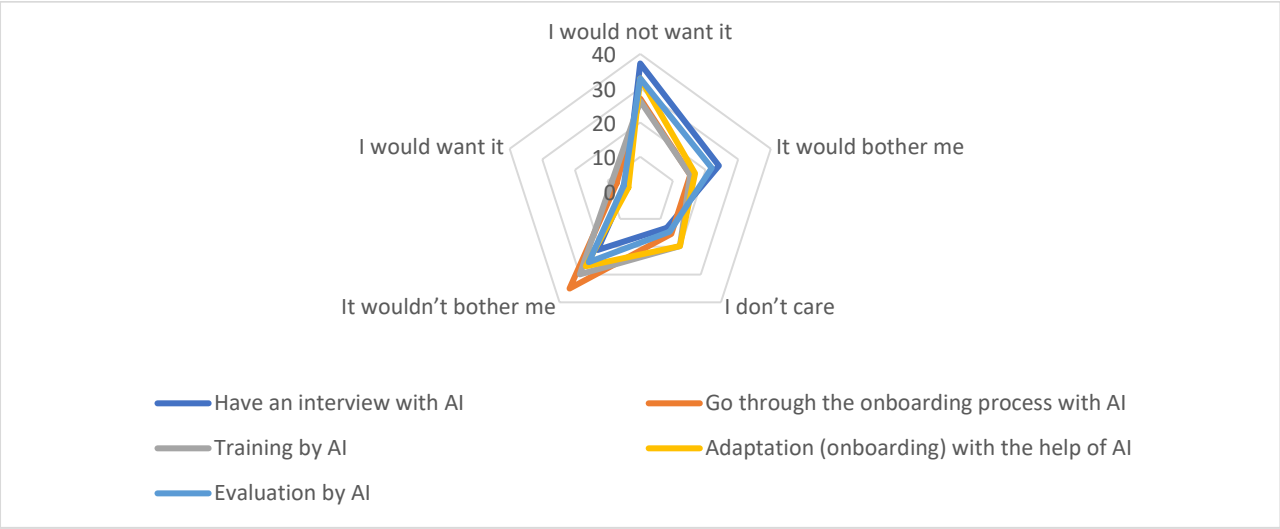


Figure 3. Use of AI in HR Processes
Source: own calculation

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 1 (September)
http://doi.org/10.9770/q2447759355

A similarly skeptical attitude is evident in relation to AI-based performance evaluation, where 135 respondents (33%) stated that they would not want their performance to be assessed in this way. An additional 90 respondents (22%) indicated that they would find such an approach undesirable and would prefer an alternative. These results suggest that people are concerned about the lack of personal interaction, objectivity, and fairness in assessment and selection processes.

On the other hand, respondents showed a slightly more positive attitude toward HR processes such as onboarding, training, and adaptation. For instance, with respect to an AI-assisted onboarding process, 144 respondents (35%) reported that it would not bother them, and 30 (7%) stated that they would actually prefer it. In the case of training supported by AI, 123 respondents (30%) indicated that it would not be a problem, while 36 (9%) said they would welcome it. These findings suggest that AI is primarily perceived as a practical tool in administrative and educational tasks, where it can streamline processes without interfering with personal relationships.

Overall, it can be concluded that respondents are cautious toward the use of AI in HR processes, particularly in activities that require personal interaction or performance evaluation. However, AI is regarded as more acceptable as a support tool in onboarding and training processes. For HR managers, this highlights the need for a sensitive approach to the implementation of AI technologies, especially in contexts where they can provide support without undermining trust and the human dimension of work.

Table 2. Respondents' Concerns about AI Replacement

												Together	
		Yes		Partially		Not thinking		Rather no		no			
		n	%	n	%	n	%	n	%	n	%	n	%
Gender	Mans	3	2	27	22	12	10	51	42	30	24	123	100
	Females	30	10	93	32	39	14	60	21	66	23	288	100
Together		33	8	120	29	51	13	111	27	96	23	411	100

Source: own calculation

The survey indicates that concerns about being replaced by artificial intelligence at work are present, but not predominant. Only 8 respondents (1.9%) reported being definitely afraid of replacement by AI—of these, 3 were men (2% of men) and 30 were women (10% of women). Another 120 respondents (29%) expressed partial concerns, with women again reporting a higher level of uncertainty (93 women, 32%; 27 men, 22%).

Interestingly, 51 respondents (13%) stated that they had not considered this question, which may suggest either low awareness or a lack of interest in the topic of AI in the workplace. On the other hand, 111 respondents (27%) reported that they were rather not concerned, with men showing lower levels of concern (51 men, 42%; 60 women, 21%). In addition, 96 respondents (23%) reported that they were not concerned at all (30 men, 24%; 66 women, 23%).

From a gender perspective, it is clear that women express concerns more frequently than men—whether complete, partial, or hesitant. Men are more likely to choose responses such as "rather not" or "not at all," which suggests a higher degree of certainty or confidence in their job stability. While most respondents do not feel significant anxiety about being replaced by AI, the survey highlights gender differences. Women appear to be more cautious toward AI in the workplace, which may be related to the nature of their job positions, lower technical orientation, or concerns about automation. For HR managers, it is important to recognize these differences and to ensure transparent communication, provide employee training, and strengthen trust in new technologies when introducing AI into the workplace.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 1 (September)
http://doi.org/10.9770/q2447759355

Subsequently, the data obtained from the survey were subjected to statistical verification. Based on the theoretical framework, the following hypotheses were formulated:

H0: There is no statistically significant difference between men and women in terms of concern about AI replacement.
H1: There is a statistically significant difference between men and women in terms of concern about AI replacement.

First, the relationship between gender and concerns about AI replacement was tested using the Chi-square test. The results are presented in Table 3.

Table 3. Chi-Square test

Chi-Square Tests			
	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	24.646[a]	4	.000
Likelihood Ratio	25.508	4	.000
N of Valid Cases	411		
a. 0 cells (0,0%) have expected count less than 5. The minimum expected count is 9.88.			

Source: own calculation

Based on the results of the Chi-square test, we can conclude that the p-value = 0.000 is significantly lower than the standard significance level of 0.05, which indicates that the differences in responses between men and women are not random. In other words, there is a statistically significant relationship between gender and respondents' concerns about AI replacement in the workplace. This result confirms that gender influences attitudes toward artificial intelligence—women feel more threatened by the use of AI, more frequently expressing concerns or uncertainty, whereas men are considerably more confident and do not perceive themselves as strongly at risk. In addition, the results were further evaluated using the Goodman and Kruskal test (see Table 4).

Table 4. Goodman and Kruskal test

Directional Measures

			Value	Asymptotic Standardized Error[a]	Approximate T[b]	Approximate Significance
Nominal by Nominal	Lambda	Symmetric	.058	.020	2.742	.006
		Gender Dependent	0.000	0.000	.[c]	.[c]
		Concerns Dependent	.082	.029	2.742	.006
	Goodman and Kruskal tau	Gender Dependent	.060	.023		.000[d]
		Concerns Dependent	.017	.007		.000[d]
Ordinal by Ordinal	Somers' d	Symmetric	-.205	.040	-4.970	.000
		Gender Dependent	-.158	.032	-4.970	.000
		Concerns Dependent	-.289	.057	-4.970	.000

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

c. Cannot be computed because the asymptotic standard error equals zero.

d. Based on chi-square approximation

Source: own calculation

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 1 (September)
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The Goodman and Kruskal tau indicates dependence by gender: 0.060, $p = 0.000$, and dependence by concern: 0.017, $p = 0.000$. This measure reflects the proportion of variability in one variable that can be explained by the other. The values are low, which means that the predictive power is weak, although the results are statistically significant. Gender explains 6% of the variability in concerns, while concerns explain only 1.7% of the variability in gender.

Table 5. Mann-Whitneyho U test

Test Statistics[a]

	transcoded Concerns
Mann-Whitney U	14161.500
Wilcoxon W	21787.500
Z	-3.320
Asymp. Sig. (2-tailed)	.001

Source: own calculation

Similarly, the Mann–Whitney U test revealed a statistically significant difference between men and women in the level of concern about being replaced by artificial intelligence at work. Since the p-value is lower than 0.05, we can reject the null hypothesis and conclude that there is a significant gender difference in attitudes toward AI replacement—women exhibit a higher level of concern than men.

5. Suggestions and recommendations

The results of the survey provided new insights into employees' attitudes toward the use of artificial intelligence (AI) in the workplace. Based on these findings, we identified several specific recommendations that employers and organizations should consider when planning and implementing AI tools within their HR processes. One of the main findings of the research was that employees need to be better informed about what artificial intelligence represents in the work environment, what its benefits and limitations are, how it functions, and how it may affect their daily tasks. We therefore recommend that organizations, prior to the implementation of AI tools, conduct information campaigns, training sessions, and workshops that clearly explain the purpose, operation, and practical benefits of these technologies in an accessible manner. Such an approach can help dispel prejudices, reduce concerns, and increase employees' trust in new solutions. At the same time, it strengthens employees' ability to use AI effectively in practice, thereby enhancing the success of its implementation.

The introduction of AI should not be abrupt or applied indiscriminately. Survey respondents perceive the use of AI most positively in relation to routine and administrative activities—such as onboarding processes, employee training, or integration into the work team. AI may also be effectively utilized for information retrieval and verification. These areas represent an appropriate entry point for the adoption of artificial intelligence.

Conversely, in personal interactions such as job interviews or performance evaluations, the presence of a human should be maintained. In such cases, AI may be perceived as impersonal or even unethical, potentially undermining employees' trust in their employer. Employees expect that decisions regarding hiring or termination, for example due to poor performance, should be made by a human.

For the successful acceptance of AI in the workplace, building transparent processes is essential. Employees should be informed about where and how AI is applied, what decisions it influences, and how they can participate in its evaluation. Equally important is creating a space for feedback, where employees can share their experiences, concerns, or suggestions.

Employers should also continuously assess the effectiveness and impact of AI solutions on the work environment. If evidence shows a negative effect on interpersonal relations, motivation, or employee performance, organizations need to respond flexibly—by adjusting the system or suspending its use.

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2025 Volume 13 Number 1 (September)
http://doi.org/10.9770/q2447759355

Conclusions

The Chi-square test confirms that the differences between men and women in their attitudes toward AI are statistically significant. For HR managers, this implies that the implementation of AI technologies must take into account gender-based differences in risk perception, ensuring that changes are communicated sensitively and that adequate training and support are provided, particularly to groups that express higher levels of concern. From a human resource management perspective, sectors with a higher proportion of employees and a greater frequency of AI usage offer more opportunities for the development of intelligent HR tools—for instance, chatbots, predictive turnover analytics, automated candidate evaluation, or workforce scheduling. Conversely, less digitalized sectors may gain a competitive advantage through the targeted implementation of AI solutions, enabling them to manage human resources more efficiently even with limited capacities.

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INNOVATION PERFORMANCE AS A SIGNIFICANT FACTOR IN THE CONVERGENCE PROCESS OF THE V4 COUNTRIES

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Abstract. Innovation constitutes a fundamental pillar of economic development, particularly within the framework of the knowledge-based economy, which prioritizes the creation of high added value through research and development (R&D). Within the European Union, innovation performance is increasingly acknowledged as a critical determinant of national competitiveness, economic prosperity, and regional convergence. This study examines the interrelationship between innovation performance—measured by the Summary Innovation Index (SII) and economic wealth, represented by GDP per capita and GDP per capita in purchasing power standards (PPS), across the Visegrad Four (V4) countries, all of which acceded to the European Union in 2004. Utilizing quantitative methods, primarily regression and correlation analyses, the research identifies statistically significant associations among innovation performance, R&D investment, and selected economic indicators. The findings reveal substantial disparities in innovation capacity among the V4 countries and highlight uneven progress in their convergence with the more established EU member states. Beyond the prevalence of declarative political commitments to fostering a knowledge economy, the results underscore the urgent need for targeted policy interventions aimed at enhancing innovation performance and accelerating the convergence trajectory of the V4 region.

Keywords: convergence; innovation; innovation performance; knowledge-based economy; research and development; Visegrad group countries

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JEL Classifications: O11, O30

1. Introduction

Explaining why some economies grow faster and become more prosperous than others has been a central concern since Solow's neoclassical growth model first formalized the role of factor accumulation over half a century ago. Subsequent research increasingly emphasizes that technological change and innovation, rather than capital deepening alone, are the decisive engines of sustained growth and convergence (González, Guimaraes & Diele-Viegas, 2025). In particular, the capacity of latecomer economies to absorb, adapt, and generate new technologies has been identified as a key determinant of catch-up, shifting attention from investment volumes to innovation capabilities (Fagerberg, 2010; Al-Omoush & Gomez-Olmedo, 2024; Ahmed, Piccinetti & Rezk, 2024).

Schumpeter framed innovation as the dynamic force of capitalism—new combinations introduced by entrepreneurs that transform production, organization, markets, and ultimately economic structures. His contribution underscores innovation as an economic process (not merely invention), highlighting its disruptive role and the entrepreneurial agency behind it (Schumpeter, 1934; Mirvis, 2024).

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/s9224378992

The Oslo Manual—jointly issued by the OECD and Eurostat—provides the international standard for defining and measuring innovation. The third edition (2005) crystallized the now-canonical four types of innovation (product, process, marketing, organizational), while the fourth edition (2018) broadened scope and updated concepts and guidance for cross-country comparability (OECD & Eurostat, 2005; OECD & Eurostat, 2018). Innovation can be understood as both a product/outcome (e.g., new goods, services) and a process (e.g., new production or delivery methods). Product innovations often differentiate firms and reshape market structures, while process innovations target cost, quality, and efficiency improvements—together enabling competitive repositioning and productivity gains (Lofsten, 2014; OECD & Eurostat, 2018; Li et al., 2024).

The European Innovation Scoreboard that is based on the Summary Innovation Index (SII) provides a comparative assessment of national innovation systems across the EU. Commonly merging indicators:

- Human resources in the area of science and technology (% of population)
- Participation in lifelong education (age of 25-64 years)
- Public expenses for research and development (% GDP)
- Company expenses for research and development (% GDP)
- Employment in medium-tech and high-tech production (% of overall work force)
- Employment in high-tech services (% of overall work force)
- Patents registered in The European Patent Office (per one m. citizens).

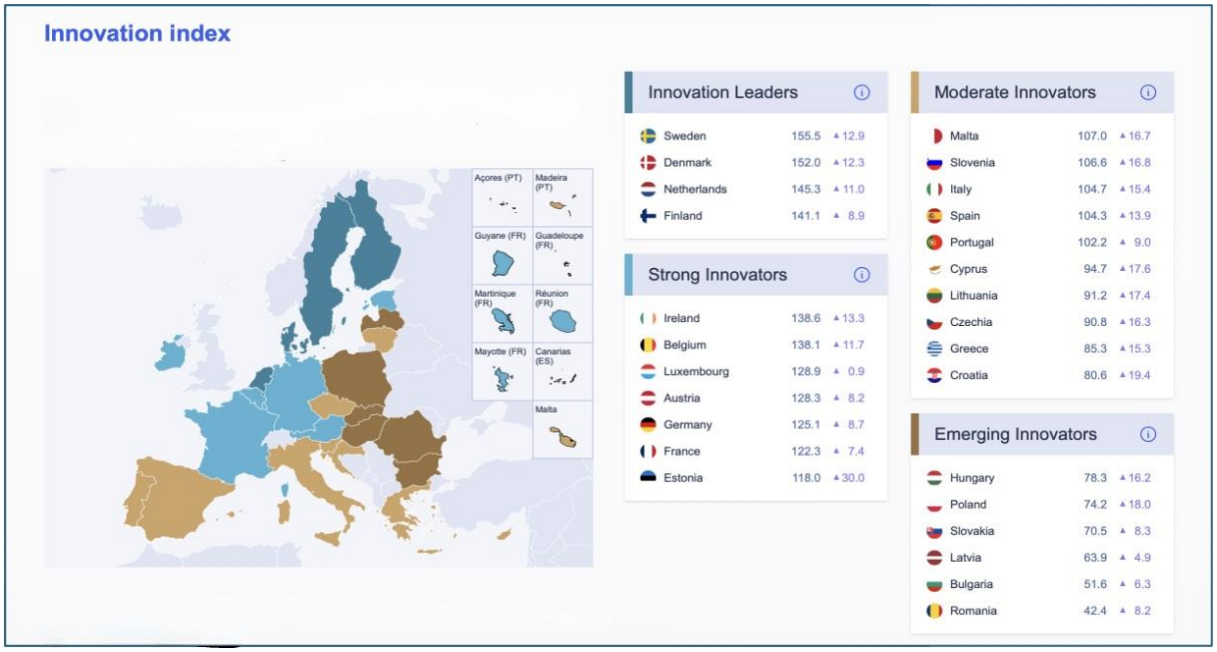


Fig. 1. Innovation performance of the European countries, 2025
Source: The European Innovation Scoreboard interactive tool (2025)

Figure 1 illustrates that the leading innovators within the European Union are predominantly Nordic countries, namely Sweden, Finland, Denmark, and the Netherlands. Hunady at al. (2022) perceive digital transformation as one of the essential sources of success of the Nordic countries. Digital innovations and e-knowledge deliver through the mechanism of digital infrastructure linkage and contribute to improved innovation performance (Janusz & Kowalczyk, 2022; Hussain, Jun & Radulescu, 2024). Within the Visegrad Group, only the Czech Republic attains the status of a moderate innovator, whereas the remaining member states are classified among the least innovative economies, categorized as emerging innovators.

In May 2004, Slovakia, Czech Republic, Poland, and Hungary joined the European Union as part of the largest enlargement in EU history, which integrated ten new Member States from Central and Eastern Europe. This accession marked a significant step toward political and economic integration, opening access to the single market and structural funds. From a convergence perspective, EU membership should accelerate the process

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/s9224378992

of real and nominal convergence, enabling these economies to narrow income and productivity gaps with older member states through increased trade, foreign direct investment, and institutional reforms aligned with EU standards. According to endogenous growth theory, innovation enhances productivity and accelerates structural transformation, enabling less developed economies to catch up with more advanced members. This article is focusing on the role of innovation performance in the economic convergence of Visegrad Four (V4) countries.

2. Literature review

In July 2022, the European Commission adopted the New European Innovation Agenda, which aims to position Europe at the forefront of deep-tech innovation and accelerate the scaling up of innovative companies. This agenda introduces five flagship areas—such as funding scale-ups, enabling innovation through experimentation, and fostering talent—and outlines 25 concrete actions to strengthen innovation ecosystems and address the innovation divide across the EU. It builds on previous strategies but reflects updated priorities like the green and digital transitions, resilience, and global competitiveness. Another important document is The European Industrial Strategy, updated in 2020 with recovery goals after the COVID pandemic. This document confirmed the Lisbon Strategic Aim to increase the investment ratio into science, research and innovation at least on the level of 3% GDP of the member countries.

To reach the set innovation goals the EU has proposed these following measures:

1) to continue in investments into innovation regardless of saving measures;
2) to improve the quality of Europe and individual state internal systems of research and innovation;
3) to modernize educational systems at all levels;
4) to use the EU research area for improving cooperation of innovators and researchers;
5) to simplify the approach towards European programs;
6) to commercialize innovations – improve the links among scientists and enterprises;
7) to dispose of the barriers restricting the introduction of new ideas into market – more functions for the SMEs sector;
8) to establish European partnerships this would support and accelerate the research, development and introduction of innovations to the market;
9) to improve innovations in the public sector;
10) to support the cooperation with international partners and open up the opportunity of the EU support programs.

It is important to note that the economies of the greatest innovators among European countries are strongly focusing in their key strategic documents on sustainable and "green" economic growth. Globocnik, Rauter and Baumgartner (2020) also emphasize the importance of the sustainability-related innovation orientation of the economy. Sustainable economy plays an important role of the covid-recovery financial help from the European Union – e.g., in Slovakia, the largest amount of financial support of the Covid-recovery plan will be used for support of the sustainable and "green" economy projects. Trainer (2022) however pointed out the practical unattainability of these green goals and their negative economic impact. Childs and Triantis (1999) examined different R&D investment policies and their success in fulfilling the goals – results could be also used as basics for evaluation of the sustainability-related innovation policies. Carboni and Medda (2020) offer tools for the evaluations of internal enterprises´ policies on the micro-level. Hafezali et al. (2020) modeled the impact of R&D expenditure on GDP growth in the EU under broad conditions of globalization. Regional development from the perspective of R&D expenditure was examined in the research made by Woo, Kim and Lim (2017). Hong (2017) in his research based on data from South Korea identified a link between the volume of R&D expenditure and the country's economic growth. Kamasak (2015) with other factors impacting innovation performance mentioned also R&D investments. Kučera and Fiľa (2022) confirmed a precondition that a higher % of expenditure into research and development increases also the innovation performance of an individual country. A typical example is Sweden which in long term spends on research and development in the comparison with the GDP the largest financial amount and so it represents the leader in innovation performance among the EU member states in long term. Albulescu and Draghici (2016) pointed out that higher business support alone does not mean higher innovation performance. From this perspective, it is crucial to support the R&D also by public funds and not only by private financial sources.

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2025 Volume 13 Number 2 (December)
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Wang and Thornhill (2010) are focusing on ways how the R&D development could be financed on micro-level. Among the innovation performance and wealthiness of the countries there is a precondition of correlation and therefore a higher innovation performance leads to higher wealth of the country (measured by the real GDP per capita). Endo and Ikeda (2021) focused in their research on ways how the wealthy countries are reaching the already mentioned sustainable development. The issue of wealth inequality between countries was well examined in the research made by Pfeffer and Waitkus (2021). Impact of the countries´ wealth on happiness of the population was assessed by Senik (2014). Ketchen, Ireland and Snow (2007) examined different types of enterprises and their contribution to total wealth by using collaborative innovation. Azpitarte (2012) in addition to the countries´ wealth also examined the impact on salaries. Hamilton and Hepburn (2014) mentioned in their research that GDP per capita should not be the only one indicator of wealth. Fessler and Schurz (2018) pointed out that welfare state and its higher expenditures from public funds in fact goes along with an increase of observed wealth inequality. Gok and Peker (2017), Rajapathirana and Hui (2018) in their research indicated the positive connection between market performance and innovation performance. Innovation policy of the EU is based on the support of enterprise sphere. This helps to contribute towards better industrial performance and so to support meeting broader social objectives such as industrial growth, increased employment rate and competitiveness of the industry within society and its sustainability. Fila (2017) perceives innovations as core of development of modern knowledge-based economy. Innovations in the born micro, small, and medium enterprises also contributes to sustainable economy growth (Mura et al., 2024; Hunková & Havierniková, 2024; Zainuri et al., 2025).

The economic growth theories indicate that GDP growth depends on capital increase, investments and from the increase of the workforce through population growth. Modern economic theories of the 20th century attributed the important role of GDP growth to technological progress (Solow´s neoclassical growth model, Barro´s and Romer´s model). Romer (1993), within the endogenous growth theory, assumed that poor countries should adopt the technologies of better developed countries for faster economic growth. Higher R&D expenditures are a basic precondition for faster economic growth which is basically represented by GDP per capita. Technological progress has a significant impact on GDP and rapid/jump growth is not possible without innovation. The concept of convergence has been central to the European Union's (EU) integration process, serving as both a prerequisite for monetary union and a long-term objective for economic cohesion. Convergence in the EU context is multidimensional, encompassing nominal convergence, which refers to compliance with macroeconomic stability indicators, and real convergence, which denotes the gradual alignment of income levels and living standards across member states.

The Maastricht Treaty (1992) established the formal convergence criteria—commonly known as the Maastricht criteria—as conditions for adopting the euro. These criteria include: (i) price stability, measured by inflation rates not exceeding 1.5 percentage points above the three best-performing Member States; (ii) sound public finances, requiring a government deficit below 3% of GDP and public debt below 60% of GDP; (iii) exchange rate stability, demonstrated by participation in the Exchange Rate Mechanism (ERM II) for at least two years without severe tensions; and (iv) convergence of long-term interest rates, which should not exceed by more than 2 percentage points those of the three best-performing member states in terms of price stability. Nominal criteria were designed to ensure macroeconomic stability and prevent asymmetric shocks within the Economic and Monetary Union (EMU).

While nominal convergence is a legal and institutional requirement for euro adoption, real convergence—the process by which less developed economies catch up with more advanced ones in terms of GDP per capita—remains a broader economic goal. Real convergence is often assessed through two complementary concepts: β-convergence, which occurs when poorer economies grow faster than richer ones, and σ-convergence, which refers to a reduction in income dispersion across countries (European Central Bank (ECB), 2015). Empirical evidence suggests that while Central and Eastern European (CEE) countries have experienced significant real convergence since their accession to the EU, disparities persist, particularly among euro area members where structural rigidities and institutional weaknesses have hindered sustained convergence (ECB, 2015).

Solow (1956) stated that theoretical underpinnings of convergence trace back to the neoclassical growth model, which predicts conditional convergence based on diminishing returns to capital and technology diffusion.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/s9224378992

Romer (1993) by endogenous growth theories emphasized the role of innovation, human capital, and institutional quality in sustaining long-term convergence. Within the EU, economic integration—through the single market, structural funds, and cohesion policy—has been expected to accelerate convergence by facilitating capital flows, trade, and labor mobility (Alcidi, 2019). However, the global financial crisis and subsequent euro area debt crisis revealed that nominal convergence prior to euro adoption does not automatically guarantee real convergence, highlighting the importance of structural reforms and productivity growth (Bukowski, 2006; ECB, 2015). Beyond the EU, the notion of convergence has been widely studied in global economic literature. The hypothesis of absolute β-convergence posits that poorer countries grow faster than richer ones, leading to income equalization over time, while conditional β-convergence accounts for differences in structural characteristics such as savings rates, population growth, and institutional quality (Barro & Sala-i-Martin, 1992). Martinho (2023) confirmed partial convergence trends globally, though the pace and sustainability of convergence vary significantly across regions and periods.

In this context, overall, the literature underscores that convergence is neither automatic nor uniform. While EU policies and institutional frameworks have facilitated progress, persistent structural disparities and asymmetric shocks continue to challenge the objective of full economic cohesion. Achieving sustainable convergence requires not only adherence to nominal criteria but also long-term strategies that enhance innovation, innovation-driven productivity and institutional resilience.

3. Methodology

Regarding the identification of a possible relationship between the innovation performance (expressed by Summary Innovation Index – SII) and economic wealth of the V4 countries, represented by GDP per capita and GDP per capita in purchasing power standards (PPS), the set of hypotheses and goals shown below were set.

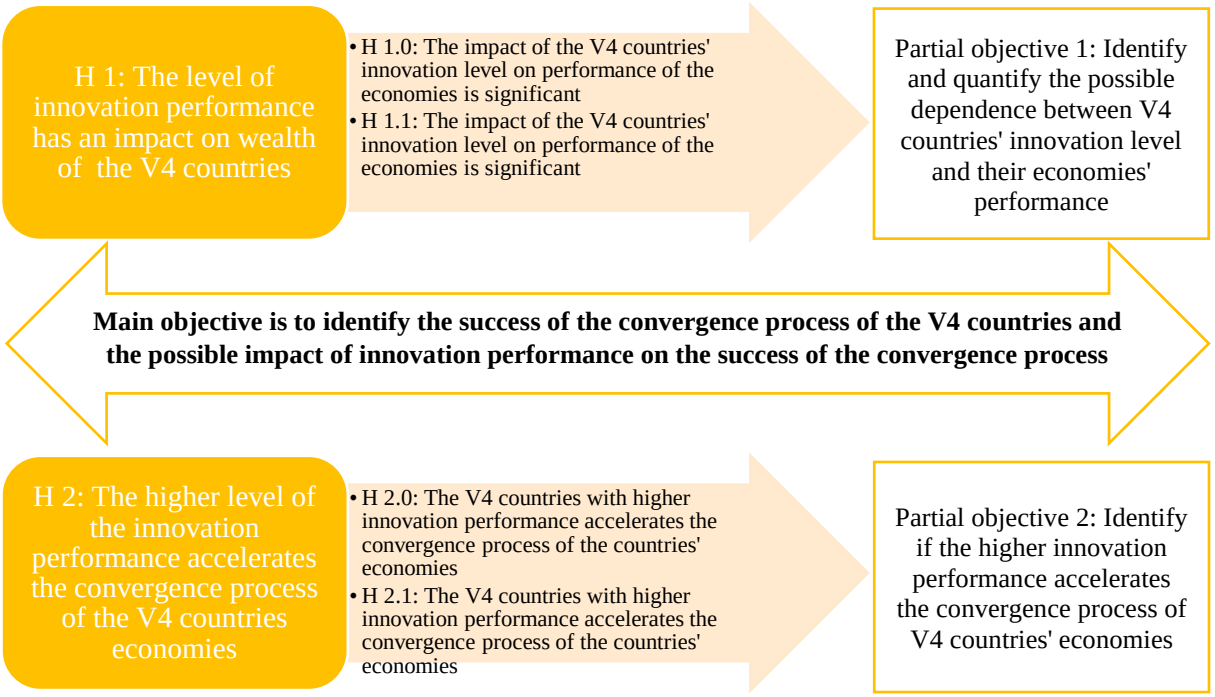


Fig. 2. A set of partial objectives and set hypotheses
Source: made by the author

The present study focuses on three core indicators: innovation performance, GDP per capita, and GDP per capita expressed in purchasing power standards (PPS) across the Visegrad Group (V4) countries. The primary objective is to assess whether innovation performance exerts a measurable influence on the economic prosperity of these countries and to determine the extent to which innovation performance contributes to accelerating the

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
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convergence of V4 economies toward the European Union average, as reflected in GDP per capita and GDP per capita in PPS.

The analysis relies on secondary data drawn from the European Innovation Scoreboard (covering the period 2004–2025 for innovation performance across EU Member States) and complementary datasets from Eurostat (2004–2024 for GDP per capita and 2013–2024 for GDP per capita in PPS).

Empirical, exploratory, comparative and statistical methods of examining secondary data were used to meet the partial as well as main objectives of the research. The analytical tools used include the comparative analysis, the regression and correlation analysis. These analyses will allow us to confirm or refute the hypothesis. The regression analysis (in identified linear functions) examines a possible relationship between two variables, where we assume that:

A. the value of the dependent variable (Y – GDP per capita) is affected by a change in the value of an independent variable (X – innovation performance). Regression formula is: GDPpcit=β0+β1·SIIit+εit

- GDPpcit: GDP per capita for country ii in year tt (in EUR).
- β0: Intercept (baseline GDP per capita when SII = 0).
- β1: Effect of SII on GDP per capita (change in EUR for a 1.0 increase in SII).
- SIIit: Innovation performance index (0–1).
- εit: Random error term (captures unobserved factors).

B. the value of the dependent variable (Y – GDP per capita in PPS) is affected by a change in the value of an independent variable (X – innovation performance). Regression formula is: PPSit=α0+α1·SIIit+uit

- PPSit: GDP per capita in Purchasing Power Standards (index, EU27 = 100).
- α0: Intercept (baseline PPS index when SII = 0).
- α1: Effect of SII on PPS index (change in index points for a 1.0 increase in SII).
- SIIit: Innovation performance index (0–1).
- uit: Random error term (captures unobserved factors).

To build a 10-year projection of the innovation performance (SII) for each V4 country, by 2034, which could help reach the EU average level of GDP per capita indicator (GDP per capita in PPS is not suitable for the prediction because it is the normalized Eurostat index) a formula will be used (in simplified form):

$$SII = \frac{\text{GDPpc (EU 2034)} - \alpha c}{\beta c}.$$

Not every innovation or type of innovation contributes equally to innovation performance or economic growth. From this point of view, we do not methodologically monitor the contribution of individual components of innovation or their number, but we monitor the contribution of the overall innovation performance of selected countries. The impact of innovation performance on the acceleration of convergence among the V4 countries will be assessed through a comparison of the values of innovation performance indicators and GERD investment, as well as GDP per capita and GDP per capita in PPS for the V4 countries and the EU average.

Limitations of the research made lies in the fact that the theory of economic growth is relatively complex, evolves over time and it is possible to express economic growth by many indicators or factors. This research abstracted from factors such as the quality of the environment, length of working time etc., and focus only on the basic key indicator expressing economic growth – the GDP per capita and GDP per capita in PPS.

ENTREPRENEURSHIP AND SUSTAINABILITY ISSUES
ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/s9224378992

4. Impact of the innovation performance on the wealth and convergence of the V4 countries

After the initial analysis through visual assessment using X to Y we chose a suitable mathematical function of which the curve best reflects the relationship between observed variables. In both cases – dependence between innovation performance and GDP per capita and GDP per capita in PPS, a linear function showed preferable, which suggests that both chosen wealth indicators rise with rising innovation performance in linear way. The sample has 80 country–year observations (4×20) – in the case GDP per capita 256ependence and 44 country-year observations (4×11) – in the case GDP per capita in PPS dependence (see Table 1 below).

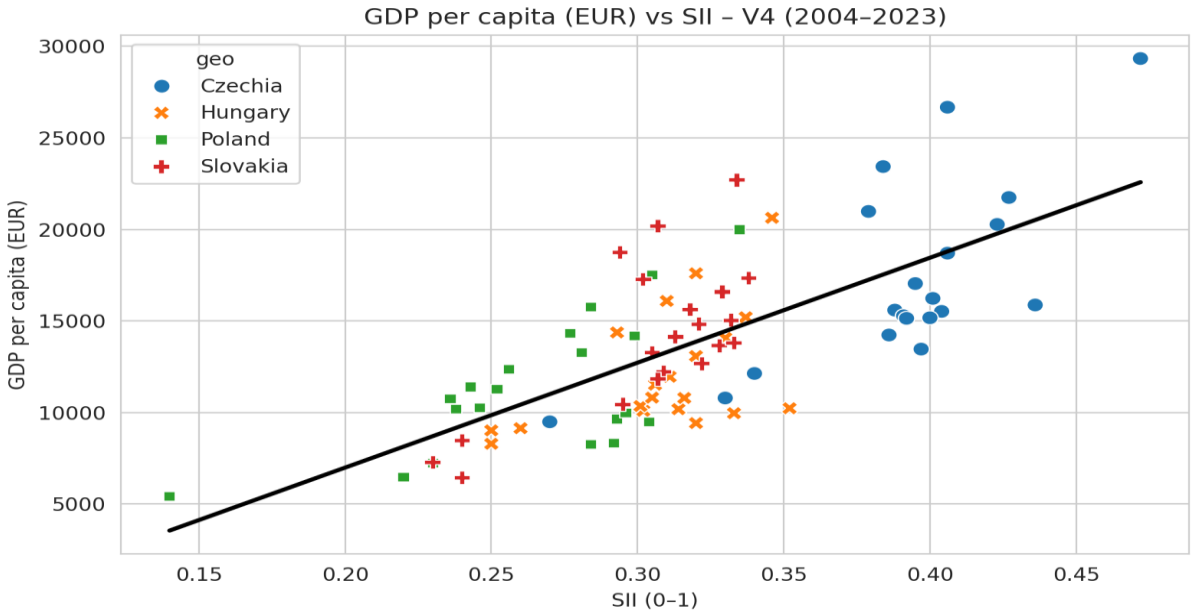
Table 1. Correlations (Pearson)

Pair	r
GDP per capita ↔ SII	**0.720**
GDP in PPS index ↔ SII	**0.835**

Source: made by the author

According to the Pearson's correlation coefficient and Cohen's interpretation of the correlation coefficient, there is:

1. a big positive dependence between the GDP per capita indicator and the level of innovation performance,
2. a big positive dependence between the GDP per capita in PPS indicator and the level of innovation performance.



ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/s9224378992

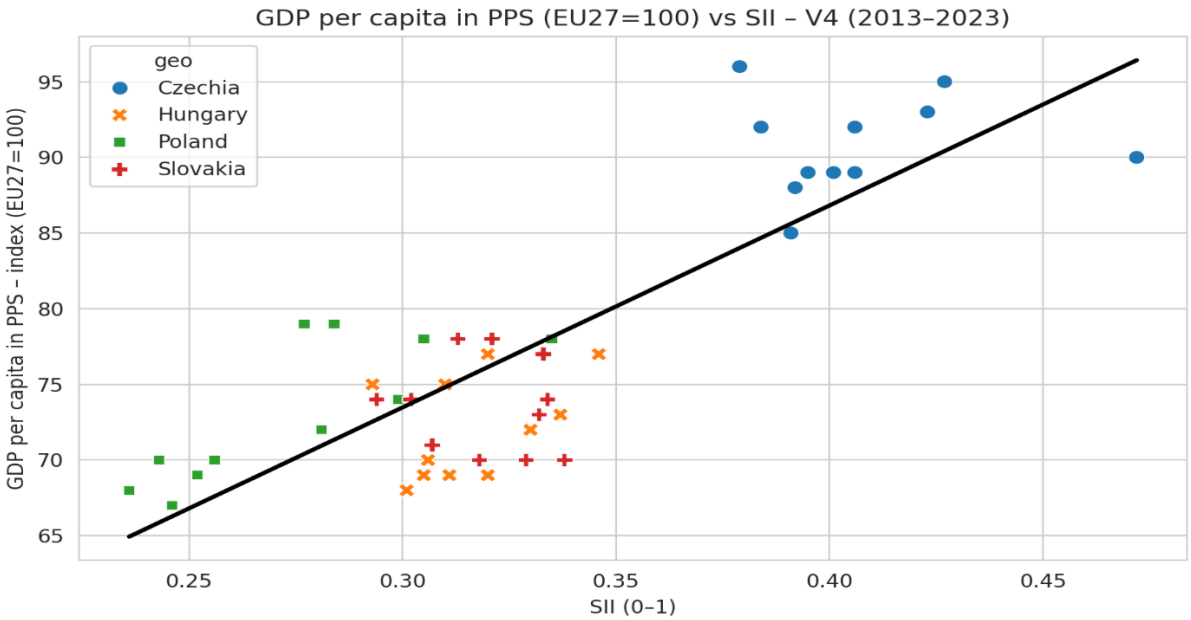


Fig. 3. Linear regression graphs
Source: made by the author

The Figure 3 shows linear regression graphs which illustrates the relationships between the GDP per capita and GDP per capita in PPS indicators with the level of innovation performance (represented by SII index).

In the case of the GDP per capita indicator, there is a strong positive slope: points trend upward—countries/years with higher innovation performance (SII) tend to show higher GDP per capita (EUR).

Country clustering:

- Czechia generally sits in the upper-right (higher SII, higher income).
- Poland and Hungary cluster mid-band and trend upward over time.
- Slovakia lags somewhat on both axes in several years, with visible progress but more volatility.

There is a dispersion around the line: The y-axis is nominal GDP per capita, so price inflation, exchange-rate swings, and cyclical shocks (e.g., COVID-19 pandemic 2020–2022) can pull points above/below the trend even when SII moves smoothly. Country-specific traits (tax structure, industrial mix) also shift points vertically.

The cross-section + time pooled relationship is clearly positive: higher SII goes hand-in-hand with higher income levels across the V4 timeline. Within a single country, the year-to-year income response to SII can be masked by macro shocks and price effects—so the tightness of the cloud is not uniform across countries/periods.

In the case of the GDP per capita in PPS indicator the cloud is typically tighter and more linear than the previous one. As SII rises, the PPS index also rises. Country placement is similar (Czechia toward the upper-right), but the spread around the line is smaller. Why this plot is tighter because the PPS index removes cross-country price-level differences and dampens inflation/exchange-rate shocks, so it aligns more closely with structural productivity.

Innovation performance is closely aligned with GDP per capita in PPS Even after stripping out country idiosyncrasies and common year shocks, improvements in SII tend to coincide with higher GDP per capita in PPS within countries over time in 2013–2023.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/s9224378992

Table 2. Regression output – predictions

TERM	COEF.	ROBUST SE (HC3)	P VALUE
DEPENDENT VARIABLE: GDP PER CAPITA (EUR) — PREDICTOR OF INTEREST: SII			
SII (0–1)	**39,565.21**	7,896.87	5.44×10^{-7}
DEPENDENT VARIABLE: GDP PER CAPITA IN PPS (EU27 = 100) — PREDICTOR OF INTEREST: SII			
SII (0–1)	**85.51**	16.22	1.36×10^{-7}

Source: made by the author

For both models, as it is shown on the Table 2, the p-values are extremely small ($p < 0.001$), which means the probability of observing such strong associations by random chance is less than 0.1%. This provides very strong statistical evidence that innovation performance (SII) is positively associated with both nominal GDP per capita and GDP per capita in PPS in the V4 countries. Interpretation of coefficients:

- **GDP per capita (EUR)**
  A 0.10 increase in SII (on a 0–1 scale) is associated with an increase of about **3,957 €** in GDP per capita, holding other factors constant.
- **GDP per capita in PPS**
  A 0.10 increase in SII corresponds to an increase of about **8.6 index points** in PPS, which is a substantial improvement compared to the EU average.

As previously indicated, there is a logical and direct relationship between innovation performance and investments in R&D. Over the long term, the Czech Republic has consistently allocated the highest percentage of its GDP to R&D. Poland, however, has also steadily increased its investment volume over time, followed by Hungary and the Slovak Republic. The following graph illustrates the evolution of resources invested in R&D since the accession of the V4 countries to the European Union.

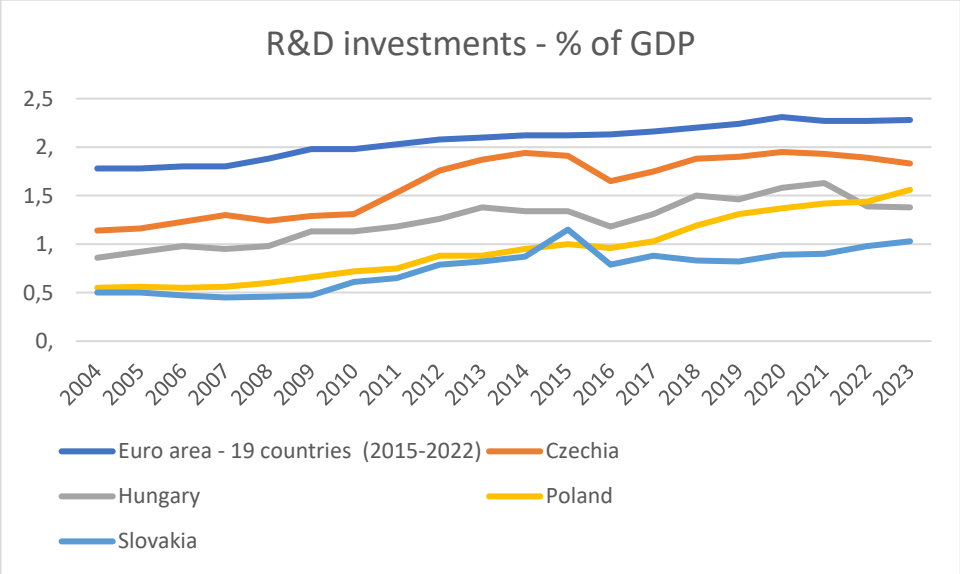


Fig. 4. R&D investments covering the year period 2004-2023
Source: made by the author based on EUROSTAT data sets

The Czech Republic is the leader among the V4 countries in terms of innovation performance and the volume of resources invested in research and development (% of GDP). It is also the country that has achieved the greatest convergence toward the EU average in living standards since its accession, as measured by GDP per capita and GDP per capita in PPS indicators. The table below presents the percentage values of innovation performance, the volume of resources invested in research and development, GDP per capita, and GDP per capita in PPS relative to the average of the original EU member states in selected years.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/s9224378992

Table 3. Percentage of the EU average in the selected set of indicators from 2004 until now

R&D	**2004**	**2023**
Czechia	64,04%	80,26%
Hungary	48,31%	60,53%
Poland	30,90%	68,42%
Slovakia	28,09%	45,18%
SII	**2004**	**2023**
Czechia	61,36%	87,73%
Hungary	56,82%	67,66%
Poland	31,82%	63,38%
Slovakia	54,55%	63,38%
GDPpc	**2004**	**2024**
Czechia	36,58%	66,79%
Hungary	31,96%	48,93%
Poland	20,89%	51,18%
Slovakia	24,79%	54,45%
GDPpc PPS *(measured from 2013*	**2013**	**2024**
Czechia	78,70%	87,50%
Hungary	62,96%	74,04%
Poland	62,04%	75,96%
Slovakia	71,30%	72,12%

Source: made by the author

Table 3 above presents the percentage share of selected indicators for the V4 countries relative to the average of the original EU member states. More than 20 years have passed since the V4 countries joined the European Union, yet none of them has managed to reach the average values of the original member states.

However, it was demonstrated that higher investments in R&D—and consequently higher innovation performance—enable an accelerated convergence process. Estonia also joined the European Union in May 2004. It has continuously and significantly increased its R&D investment from 0.8% of GDP in 2004 to 2.3% in 2011, and to the current level of 1.8%. It is the only post-socialist country that has reached the 'strong innovators' category, thereby substantially accelerating its convergence.

Among the V4 countries, the Czech Republic is the convergence leader, as it has consistently invested the highest proportion of its GDP in R&D and is the only country classified as a 'moderate innovator'; the others remain in the 'emerging innovators' category. Poland, thanks to its continuous increase in R&D investment, is expected to move into the 'moderate innovator' category in the near future.

Table 4. Outputs of the innovation performance raise prediction for the V4 countries

Country	**SII 2024**	**SII needed for GDP (2034)**	**Selected SII in 2034**	**Growth of the SII per year**	**Prediction GDP pc in 2034**
Czechia	0.472	0.712	**0.712**	+0.024	**47,969**
Hungary	0.364	0.774	**0.774**	+0.041	**47,969**
Poland	0.341	0.787	**0.787**	+0.045	**47,969**
Slovakia	0.341	0.635	**0.635**	+0.029	**47,969**

Source: made by the author

Table 4 above indicates that all V4 countries must significantly raise their innovation performance (SII) to reach the projected EU average levels of GDP per capita by 2034. Hungary and Poland require the largest annual SII increases (around +0.04–0.05 per year), while Czechia and Slovakia need slightly smaller but still substantial

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/s9224378992

improvements. If these innovation targets are met, each country is expected to converge to the EU-level GDP benchmark within the next decade. This highlights that sustained innovation growth is a critical driver for economic convergence in the region (see Table 5 below).

Table 5. Summary of correlation and regression analysis output

HYPOTHESES	CONFIRMATION / REFUSAL	RESULTS
H1	**YES**	The impact of the V4 countries' innovation level on performance of the economies is significant. A 0.10 increase in SII (on a 0–1 scale) is associated with an increase of about **3,957 €** in GDP per capita. A 0.10 increase in SII corresponds to an increase of about **8.6 index points** in GDP per capita in PPS, which is a substantial improvement compared to the EU average.
H 1.0	**YES**	
H 1.1	**NO**	
H2	**YES**	The V4 countries with higher innovation performance accelerate the convergence process of the countries' economies. The Czech Republic is the leader among the V4 countries in terms of innovation performance and also selected convergence indicators – GDP per capita and GDP per capita in PPS.
H 2.0	**YES**	
H 2.1	**NO**	

Source: made by the author

Table 5 summarizes the outputs of the analytical part and links them to the hypotheses and goals of the methodological part in Figure 2. The outputs of the regression analysis confirmed that the level of innovation performance has an impact on wealth of V4 countries and also that this impact is significant (0.10 increase in SII is associated with an increase of about 3,957 € in GDP per capita and with an increase of about 8.6 index points in GDP per capita in PPS, which is a substantial improvement compared to the EU average). The outputs of the analytical part also confirmed that the higher level of the innovation performance accelerates the convergence process of the V4 countries' economies and therefore the V4 countries with higher innovation performance accelerates faster the convergence process of the countries' economies (The Czech Republic is the leader among the V4 countries in terms of innovation performance and also selected convergence indicators).

Conclusions

This research provides empirical evidence that innovation performance is a critical determinant of economic prosperity and convergence within the V4 countries. The analysis confirmed a strong positive correlation between the Summary Innovation Index (SII) and both GDP per capita and GDP per capita in purchasing power standards (PPS). Specifically, a 0.10 increase in SII is associated with an approximate rise of €3,957 in GDP per capita and an increase of 8.6 index points in PPS, underscoring the significant role of innovation in accelerating economic convergence (see Table 2).

The study is unique in its comprehensive focus on the V4 countries over almost a two-decade period, combining innovation performance indicators with economic convergence metrics. Unlike previous studies that often-examined innovation or convergence in isolation, this research integrates both dimensions and provides a forward-looking projection of innovation performance required for achieving EU-level GDP by 2034. This predictive approach offers actionable insights for policymakers in the V4 region. Key findings are:

- Innovation performance and economic wealth are strongly interlinked, forming a reinforcing cycle with R&D investment.
- Among the V4 countries, the Czech Republic leads in innovation performance and convergence, while Slovakia lags behind despite moderate progress.
- Achieving EU average GDP levels by 2034 will require substantial annual increases in SII, particularly for Hungary and Poland.

The study abstracts from several other factors influencing economic growth, such as institutional quality, labor market dynamics, and environmental sustainability. Additionally, the analysis relies on secondary data, which may be subject to reporting inconsistencies. Future research can be expanded to include multifactor models

incorporating broader indicators of modern economic theory, including human capital and digitalization metrics.

The findings highlight the necessity of sustained and targeted investments in R&D, supported by both public and private sectors. Pisár and Honzová (2025) pointed out on the need of investments into e-government applications that could also speed-up the convergence process. Legislative frameworks should set measurable innovation objectives and ensure continuous monitoring and adaptation to global economic dynamics. Without such measures, the convergence process will remain slow and uneven. The legislative frameworks should also respect the cultural background and specificities of each country (Kondrla et al., 2023).

However, a significant challenge arises from the increasing pressure in the European Union to allocate up to 5% of GDP to defense spending, particularly in response to geopolitical tensions and also with the pressure to transition countries' economies to zero emissions. For countries in the convergence process, such a reallocation of resources could severely limit the fiscal space available for innovation and R&D investments. This trade-off between defence and development or CO^2 emissions-reduction and development must be carefully managed to avoid undermining long-term economic growth. Clark and Abbasi (2025) also point out another significant effect of armaments - subsequent negative impact on the health of the population due to decreasing expenditures on health. Policymakers should explore innovative financing mechanisms, EU-level support programs, and public-private partnerships to safeguard innovation funding. It is also important, in the case of defence investments, to find areas that will generate higher added value.

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DRIVERS OF FRONT-LINE SALES EMPLOYEES' RETENTION: INTERACTION, MOTIVATION, AND PERFORMANCE*

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Abstract. Employee retention is a critical dimension of organisational sustainability, particularly in sales-intensive sectors where high turnover undermines competitiveness and long-term value creation. This study examines how intangible assets, specifically, the quality of buyer–seller interaction, intrinsic motivation, and sales performance, jointly shape the sustainability of human capital in the Indian banking sector. Drawing on Self-Determination Theory (SDT) and Social Identity Theory (SIT), the research develops and tests a behavioural framework linking relational dynamics, psychological fulfilment, and performance outcomes to employee retention. A cross-sectional survey of 449 sales professionals in the Indian banking sector was analysed using Partial Least Squares Structural Equation Modelling (PLS-SEM). Results confirm that effective buyer–seller interaction significantly improves sales employee performance and directly enhances retention, while performance partially mediates this relationship. Findings highlight that autonomy, competence, and relatedness, fostered by supportive interactions, translate into superior performance and a more substantial commitment. Furthermore, individual characteristics, organisational ecosystems, and social affiliation are identified as antecedents of effective interactions, reinforcing the role of intangible resources in sustaining workforce stability. The study contributes to sustainability and organisational behaviour literature by demonstrating how relational quality and motivational processes act as strategic intangible drivers of human capital retention. Practical implications suggest that managers should invest in autonomy-supportive leadership, recognition systems, and interpersonal skill development to enhance both sales effectiveness and long-term employee loyalty. By reframing retention as a sustainability issue, the research highlights how organisations can leverage social and psychological capital to achieve an enduring competitive advantage.

Keywords: human capital sustainability; intangible assets; buyer–seller interaction; employee retention; organisational resilience

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1. Introduction

In today's highly competitive and rapidly evolving market environment, businesses across industries face a critical challenge: retaining talented and motivated sales personnel. Sales associates serve as the front-line representatives of a company, playing a vital role in driving revenue and managing client relationships. However, persistently high turnover rates within sales teams undermine organisational stability while inflating recruitment and training costs. In this study, we treat banks as sales-intensive service organisations because they operate dedicated front-line sales teams tasked with customer acquisition and cross-selling, making the retention of these employees strategically critical.

A growing body of academic research highlights the importance of the quality of interactions between buyers and sellers, which significantly shape both sales outcomes and employee satisfaction. The concept of Effective Buyer–Seller Interaction (EBSI) is defined by the presence of trust, open communication, mutual respect, and a collaborative relationship between sales representatives and their clients (Kassemeier et al., 2022; Koponen & Julkunen, 2022). Such interactions not only enhance customer satisfaction and loyalty but also boost the motivation, engagement, and well-being of sales professionals (Baptista, Mota & Santos, 2022; Burchett, Murtha & Kohli, 2023).

Despite this recognition, prior research has largely emphasised transactional outcomes of buyer–seller dynamics, often overlooking the internal psychological processes through which EBSI affects sales employee retention. This issue is particularly salient in financial services marketing, especially banking, where competition is intense, customer focus is paramount, and relationship marketing is essential for acquiring and retaining clients. In this context, sales personnel are the primary point of contact for customers, significantly influencing satisfaction and loyalty through effective engagement. Significantly, EBSI extends beyond transactional exchanges by fostering trust, rapport, and clear communication that can enhance both employee motivation and long-term organisational commitment.

Given that sales roles are inherently stressful, target-driven, and relationship-intensive, a comprehensive understanding of the determinants influencing the retention of high-performing sales professionals is essential. Accordingly, this study addresses the following central question:

To what extent does the effectiveness of buyer–seller interaction (EBSI) influence the performance of sales employees (POSE), and how does POSE, in turn, relate to sales employee retention (SER)?

2. Theoretical background

Understanding the social and psychological factors that affect employee performance and retention has become increasingly crucial in the evolving field of sales management. Among these factors, Effective Buyer–Seller Interaction (EBSI) has emerged as a central construct, closely linked to both the Performance of Sales Employees (POSE) and Sales Employee Retention (SER).

The behavioural sciences emphasise the pivotal role of social interactions and motivational processes in shaping workplace outcomes. Prior research demonstrates that trust-based interactions not only enhance job satisfaction and performance but also strengthen retention by fulfilling psychological needs for belonging, competence, and autonomy. In this regard, EBSI reflects the relational quality that fosters mutual trust, open communication, and respect, thereby generating positive effects for both employees and organisations.

Building on this foundation, recent studies have highlighted how personality traits such as extraversion and conscientiousness (Individual Characteristics, IC), supportive Organisational Ecosystems (OE), and Social Affiliation and Integration (SAI) influence the quality of buyer–seller interactions. These factors collectively shape both employee performance and retention, underscoring the interconnectedness of personal dispositions, organisational culture, and social dynamics.

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Drawing on a wide range of theoretical and empirical research that emphasises trust-centred relationships, intrinsic motivation, and supportive organisational environments, this chapter develops four core hypotheses. These hypotheses form the conceptual pillars of the study, grounded in a systematic analysis of the interplay between individual characteristics, corporate culture, motivational needs, and interpersonal dynamics.

2.1 Buyer-Seller Interaction on Sales Employee Retention

Trust-centred buyer-seller dynamics have a well-established, favourable effect on employee retention. A recent meta-analysis conducted by Canales-Ronda (2024) reveals that relational selling, encompassing elements such as trust, rapport, and effective communication, significantly enhances the job satisfaction and retention intentions of sales professionals, thereby effectively corroborating EBSI's beneficial impact on employee retention. In a parallel fashion, Zang et al. (2020) found that emphasising relationship quality in interactions results in heightened commitment and reduced turnover among sales personnel, thereby highlighting that effective interpersonal dynamics are critical for predicting SER.

Just as school-based financial programs boost student outcomes (Cannistrà, et al., 2022), supportive workplaces strengthen employee engagement and retention. The above discussion clarifies that trust-based relational selling boosts sales and employee retention, and that individual characteristics, a supportive organisational ecosystem, and strong social affiliation and integration significantly contribute to EBSI.

H1: Effective Buyer-Seller Interaction (EBSI) has a significant positive effect on Sales Employee Retention (SER).

2.2 Buyer-Seller Interaction on Sales Performance

Research grounded in SDT elucidates the affirmative impact of EBSI on sales performance outcomes. A contemporary meta-analysis conducted by Good et al. (2022) revealed that sales personnel who are intrinsically motivatedcharacterised by the presence of autonomy, competence, and relatednessexhibit superior sales results compared to their extrinsically motivated counterparts, particularly in contexts that emphasise trust-oriented relational selling (Zheng et al., 2023) revealed through parallel research that adaptive selling approaches, built on trust-filled interactions, are essential markers of improved sales effectiveness. Autonomy constitutes a fundamental motivational factor in enhancing performance outcomes. As noted by Alriyami et al. (2024), the understanding of autonomy functions as a vital mediator between organisational justice and job output, thereby illustrating its significance in motivational elements. Concurrently, Hocine et al. (2014) establish that leadership that supports autonomy fosters increased work engagement and performance within service-oriented roles, thereby substantiating that autonomy exerts a beneficial effect on the performance of sales personnel. The degree of satisfaction regarding competence persists as a vital predictor of performance achievements. V. Good et al. (2022) ascertain that motivational factors associated with competence are among the most substantial predictors of sales performance as evidenced in their meta-analytic review. In addition, Zheng et al. (2023) deliver strong evidence that backing from both clients and bosses increases sales effectiveness, supporting the earlier conjecture. Relatedness, defined as the necessity for social affiliations, constitutes a pivotal determinant of performance outcomes. Good et al. (2022) assert that interactions that foster relatedness significantly enhance both intrinsic motivation and performance metrics within sales occupations. According to Alriyami et al. (2024), relatedness serves as a mediating component in the justice-performance structure, suggesting that social support and interpersonal ties have a direct impact on employee performance. The above discussions confirm that EBSI directly enhances sales performance, and satisfaction of SDT needs autonomy, competence, and relatedness search, which exert a positive effect on POSE

H2: Effective Buyer-Seller Interaction (EBSI) has a significant positive effect on the Performance of Sales Employees (POSE).

2.3 Sales Performance in Enhancing Employee Retention

Understanding the dynamics between employee performance and retention is increasingly critical for HR professionals, particularly in sales-driven environments where retaining high-performing talent directly impacts organisational outcomes. The connection between EBSI and retention is vital for HR professionals, as retaining top talent is crucial for success. Studies reveal that performance and retention are closely connected, influenced

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by job satisfaction, engagement, and HR practices. This analysis examines the causal mechanisms and practical implications for HR strategy, informed by pertinent research. Research indicates that job satisfaction correlates with reduced employee turnover (Alsafadi & Altahat, 2021; Memon et al., 2021; Štaffenová, Kucharčíková & Tokarčíková, 2024). Contentment with HR initiatives, including training, performance evaluations, and compensation, enhances work engagement, thereby mitigating turnover intentions (Alsafadi & Altahat, 2021; Memon et al., 2021). Specifically, satisfaction with training and performance evaluations significantly promotes employee engagement, fostering emotional bonds that decrease the likelihood of turnover (Memon et al., 2021).

Given the compelling evidence linking POSE with engagement, satisfaction, and turnover intentions, it is posited that the POSE has a significant positive effect on SER.

H3: The Performance of Sales Employees (POSE) has a significant positive effect on Sales Employee Retention (SER).

2.4 Sales Performance as a Mediator Between Interaction and Retention

Effective interactions between buyers and sellers are paramount for the performance of sales personnel. Sales personnel who engage in productive exchanges with buyers are more inclined to experience a heightened sense of competence and relatedness, which are fundamental elements of intrinsic motivation (Kakkar et al., 2022). It has been demonstrated that sales representatives who believe in their competence during buyer interactions are more prone to attain high performance levels, given their talent for convincingly presenting the value of their goods and developing meaningful connections with customers (Kakkar et al., 2022). Additionally, robust interactions between buyers and sellers can enhance sales personnel's sense of independence, as they are empowered to take actions that align with their individual beliefs and objectives.

The POSE serves a significant mediating function in the linkage between EBSI and SER. Sales agents who display remarkable performance are usually more predisposed to experience job satisfaction and engagement, essential indicators of retention (Khan, Shafi & Rajput, 2020). Successful sales agents are more prone to stay with their companies, as they experience a strong sense of success and consistently receive appreciation and benefits for their input (Conde & Prybutok, 2021; Memon et al., 2021). In contrast, subpar performance may result in dissatisfaction and increased turnover, as sales employees might perceive that their endeavours are not producing the anticipated outcomes. Overall, the accumulated evidence suggests that POSE plays a crucial mediating role in linking productive EBSI to the SER, thereby underscoring the importance of fostering environments that promote substantial engagement and performance-oriented outcomes to enhance workforce stability.

H4: The Performance of Sales Employees (POSE) mediates the relationship between Effective Buyer-Seller Interaction (EBSI) and Sales Employee Retention (SER).

2.5 Theoretical Backing and Framework

To thoroughly investigate the relational and psychological dynamics that influence the retention of sales employees, this research is grounded in two complementary theoretical frameworks: Social Identity Theory (SIT) and Self-Determination Theory (SDT). Together, these frameworks provide a robust behavioural foundation for explaining how motivation and identity processes shape employee performance and retention.
Social Identity Theory (SIT), as proposed by Tajfel et al. (1979), explains how individuals derive their self-concept from membership in social groups, which in turn influences attitudes, behaviours, and interactions. Within buyer–seller environments, SIT sheds light on how individual characteristics (IC), the organisational ecosystem (OE), and social affiliation and integration (SAI) shape interaction quality and long-term relationships. Prentice et al. (2019) highlight that consumers often align their purchasing intentions with sellers or communities that reflect their identities, thereby strengthening trust and engagement. Visual cues such as profiles and reviews help customers assess similarity in traits, fostering emotional connection and loyalty. Furthermore, research by Wang et al. (2016) demonstrates that in B2B contexts, shared values and identity in communication and culture facilitate co-creation and innovation, thereby building trust and expanding brand recognition. Ali et al. (2021) similarly found that personality trait similarities, such as openness or agreeableness, between buyers and sellers enhance emotional engagement and loyalty. Collectively, SIT

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underscores that identity alignment, organisational support, and social belonging nurture trust, emotional bonds, and loyalty—key factors in sustaining employee and customer relationships in sales contexts.

Self-Determination Theory (SDT), developed by Deci and Ryan (2013), emphasises that motivation and performance are driven by the fulfilment of three psychological needs: autonomy, competence, and relatedness (Deci & Ryan, 2000; Ryan & Deci, 2017). Autonomy reflects volition and ownership of one's actions, which fosters intrinsic motivation and job satisfaction. During the COVID-19 pandemic, these principles align with organisational excellence models, such as the Deming Prize framework, which emphasise continuous improvement, participation, and feedback as drivers of performance (Vartiak, 2015).

By integrating SIT and SDT, this study explains retention as a behavioural outcome of both motivational and identity processes. While SIT highlights how group identification, affiliation, and belonging shape relational quality and loyalty, SDT demonstrates how the fulfilment of psychological needs drives intrinsic motivation and sustained performance. Taken together, these frameworks provide a comprehensive explanation of how Effective Buyer–Seller Interaction (EBSI) influences the Performance of Sales Employees (POSE) and, ultimately, Sales Employee Retention (SER).

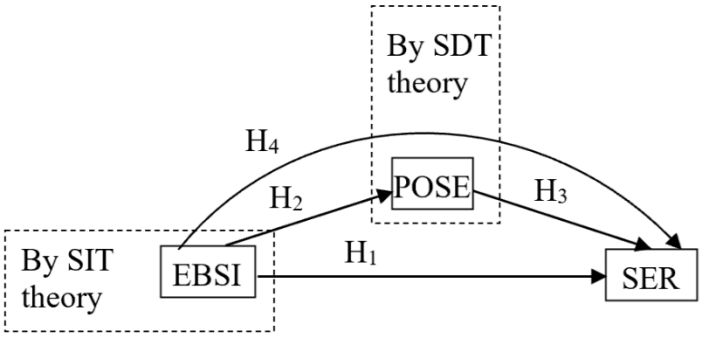


Figure 1. Theoretical framework & hypotheses
Source: own processing

3. Research objective and methodology

Building on the identified research gap and problem statement, the primary objective of this study is to investigate how Effective Buyer–Seller Interaction (EBSI) contributes to Sales Employee Retention (SER) by examining the underlying psychological and performance mechanisms involved.
EBSI is conceptualised as a behavioural construct defined by trust, mutual respect, and open communication. Specifically, this research seeks to:

1. Assess the direct impact of EBSI on SER and determine whether the Performance of Sales Employees (POSE) mediates this relationship.
2. Explore the antecedents of EBSI, focusing on three determinants: Individual Characteristics (IC), Organisational Ecosystem (OE), and Social Affiliation and Integration (SAI).
3. Examine the role of psychological needs—Autonomy, Competence, and Relatedness—outlined in Self-Determination Theory (SDT), in shaping sales employee performance and motivation.
4. Incorporate insights from Social Identity Theory (SIT) to understand how group identity and belonging further influence relational quality, motivation, and retention.

Through this integrated framework, the study aims to provide a comprehensive understanding of how relational, organisational, and psychological factors interact to enhance motivation, improve performance, and foster long-term retention among sales professionals.

This study employed a quantitative, cross-sectional survey design to examine the behavioural relationships among Effective Buyer–Seller Interaction (EBSI), Performance of Sales Employees (POSE), and Sales Employee Retention (SER). Guided by a positivist framework, the research applied Partial Least Squares Structural Equation Modelling (PLS-SEM) to test the hypothesised behavioural pathways and evaluate the

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2025 Volume 13 Number 2 (December)
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strength of direct, indirect, and mediating effects. A two-stage PLS-SEM procedure was adopted in line with methodological recommendations for assessing higher-order formative constructs (Sarstedt, 2019).

We studied front-line sales personnel in the banking segment of the financial services industry in India. Using non-probability purposive sampling, we recruited respondents with at least one year of direct, customer-facing sales experience. Data were collected via structured offline surveys administered at bank branches in India between February 2024 and June 2025. Participation was voluntary, informed consent was secured, and confidentiality was maintained. The target population consisted of front-line sales personnel in the financial services industry in India, particularly within banks. This sector was selected due to its high relational intensity and elevated attrition rates, making it an appropriate context for studying behavioural constructs of motivation, interaction, and retention. Non-probability purposive sampling was used to recruit respondents with a minimum of one year of direct customer-facing sales experience. A total of 449 valid responses were collected, satisfying the "10-times rule" of PLS-SEM, which requires a minimum sample size ten times larger than the maximum number of indicators or structural paths directed at a latent construct (Hair, 2019). This ensured sufficient statistical power and stability of model estimation.

The survey instrument was developed using standardised multi-item scales validated in peer-reviewed literature (Hair, et al., 2019; Sarstedt et al., 2019). Items were measured on a 5-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree), allowing reliable assessment of behavioural constructs. The measurement model comprised both reflective and formative constructs. Specifically:

- EBSI was conceptualised as a formative second-order construct comprising three reflective first-order dimensions grounded in Social Identity Theory (SIT): Individual Characteristics (IC), Organisational Ecosystem (OE), and Social Affiliation and Integration (SAI).
- POSE was conceptualised as a formative second-order construct comprising three reflective first-order dimensions aligned with Self-Determination Theory (SDT): Autonomy (AT), Competence (CP), and Relatedness (RLT).
- SER was treated as a reflective construct, capturing employees' long-term behavioural commitment and intention to remain with their organisations.

The questionnaire was subjected to expert review and pilot testing with 50 banking sales professionals. Feedback was incorporated to refine wording, improve contextual clarity, and ensure construct validity. Data collection was conducted through structured offline surveys administered directly at bank branches. All participants provided informed consent, and confidentiality was strictly maintained.

Data analysis was performed using SmartPLS to evaluate the reliability and validity of the behavioural constructs. Internal consistency reliability was confirmed using Cronbach's Alpha and Composite Reliability, with values exceeding the recommended threshold of 0.70. Convergent validity was established via Average Variance Extracted (AVE) (>0.50), while discriminant validity was assessed using the Fornell–Larcker Criterion and Heterotrait–Monotrait (HTMT) ratio. For the formative second-order constructs (EBSI and POSE), multicollinearity (VIF) and indicator relevance tests confirmed construct validity.

Behavioural pathways were assessed using bootstrapping (5,000 resamples) to estimate the significance of direct, indirect, and mediating effects. The Single Global Item (SGI) method (Sarstedt et al., 2019; Hair, et al., 2021) was used to verify the convergent validity of higher-order constructs, with strong and significant correlations between each formative construct and its corresponding global reflective item. R^2 values were used to assess explained variance in dependent behavioural outcomes, f^2 effect sizes to evaluate construct contribution, and Q^2 predictive relevance via blindfolding confirmed the model's predictive strength.

The research adhered to ethical guidelines, ensuring voluntary participation, anonymity, and participants' right to withdraw at any stage. This safeguarded the integrity of the behavioural data and reinforced trust in the study's findings.

4. Results and discussion

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2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/y2734537888

The study's results were derived using Partial Least Squares Structural Equation Modelling (PLS-SEM). The analysis was conducted in two phases: first, the measurement model was evaluated to establish the reliability and validity of the behavioural constructs; second, the structural model was examined to test the proposed hypotheses and assess the correlations among variables. Descriptive statistics and principal findings were analysed in line with the stated research objectives. The findings indicate that Effective Buyer–Seller Interaction (EBSI) significantly predicts both Performance of Sales Employees (POSE) and Sales Employee Retention (SER). Moreover, POSE was found to partially mediate the relationship between EBSI and SER. These results demonstrate that high-quality relational interactions enhance intrinsic motivation and foster identity alignment, which in turn sustain employee commitment and reduce turnover. The demographic characteristics of the respondents are as follows: Among 449 participants, 26.5% were aged 18 to 30 years (n = 119), 29.4% were aged 31 to 40 years (n = 132), 26.3% were aged 41 to 50 years (n = 118), and 17.8% were aged 51 to 60 years (n = 80). Regarding gender distribution, 57.7% of respondents were male (n = 259), and 42.3% were female (n = 190). This demographic distribution guarantees varied representation in terms of age and gender.

4.1 Measurement Model Assessment

The measurement model was assessed for reliability and validity before structural analysis. Internal consistency was validated by Cronbach's alpha, rho_A, and composite reliability. Convergent and discriminant validity were confirmed via AVE, item loadings, the Fornell-Larcker criterion, and HTMT ratios. Formative second-order conceptions were evaluated using outer weights, VIF, and the Single Global Item method, validating their conceptual and statistical soundness.

Table 1. Reliability and Validity Statistics of the Measurement Model Constructs

Construct	Items (Loadings)	Cronbach's α	rho_A	CR	AVE
AT	AT1: 0.852, AT2: 0.828, AT3: 0.824, AT4: 0.854	0.861	0.87	0.91	0.71
CP	CP1: 0.884, CP2: 0.835, CP3: 0.875, CP4: 0.869	0.889	0.9	0.92	0.75
IC	IC1: 0.877, IC2: 0.790, IC3: 0.839, IC4: 0.837, IC5: 0.715	0.873	0.9	0.91	0.66
OE	OE1: 0.813, OE2: 0.808, OE3: 0.776, OE4: 0.829, OE5: 0.775	0.866	0.92	0.9	0.64
RLT	RLT1: 0.852, RLT2: 0.833, RLT3: 0.896, RLT4: 0.868	0.886	0.9	0.92	0.74
SAI	SAI1: 0.796, SAI2: 0.807, SAI3: 0.801, SAI4: 0.856	0.836	0.87	0.89	0.67
SER	SER1: 0.834, SER2: 0.836, SER3: 0.809, SER4: 0.871, SER5: 0.797	0.887	0.89	0.92	0.69

Notes: EBSI = Effective Buyer–Seller Interaction; POSE = Performance of Sales Employees; SER = Sales Employee Retention; IC = Individual Characteristics; OE = Organisational Ecosystem; SAI = Social Affiliation and Integration; AT = Autonomy; CP = Competence; RLT = Relatedness; α = Cronbach's alpha; rho_A = Dijkstra–Henseler reliability; CR = Composite Reliability; AVE = Average Variance Extracted HTMT = Heterotrait–Monotrait ratio; β = standardised path coefficient; O = Original Sample; M = Sample Mean; STDEV = Standard Deviation; R^2 = explained variance; f^2 = effect size; Q^2 = predictive relevance; SRMR = Standardized Root Mean Square Residual; d_ULS = ULS discrepancy; d_G = geodesic discrepancy; NFI = Normed Fit Index; VIF = Variance Inflation Factor; PLS-SEM = Partial Least Squares SEM; SGI = Single Global Item.

Source: own research

Table 1 illustrates the reliability and validity metrics of the measurement model constructs. All constructs demonstrate remarkable internal consistency, evidenced by Cronbach's alpha (α) values between 0.836 (SAI) and 0.889 (CP), much exceeding the recommended criterion of 0.70 (Henseler, Ringle & Sinkovics, 2009). The "composite reliability" (CR) values for all constructions surpass 0.88, hence affirming construct dependability. The AVE values establish convergent validity, with all exceeding the acceptable threshold of 0.50 (Hair, Howard & Nitzl, 2020). This indicates that the latent constructs account for more than 50% of the variance in their corresponding indicators. The AVE values range from 0.64 (OE) to 0.75 (CP), indicating a moderate to high degree of shared variance among items.

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2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/y2734537888

Additionally, all individual item loadings above the criterion of 0.70 indicate strong item reliability (Fornell & Larcker, 1981). The item loadings of the construct are above 0.70, confirming its unidimensionality and internal consistency. The results confirm that the measurement model meets the essential criteria for reliability and convergent validity, thereby substantiating the appropriateness of the scales employed in this investigation.

Table 2. Discriminant Validity – Fornell-Larcker Criterion and HTMT Ratios

Fornell-Larcker criterion							
	AT	CP	IC	OE	RLT	SAI	SER
AT	0.84						
CP	0.342	0.866					
IC	0.263	0.222	0.813				
OE	0.082	0.14	0.545	0.8			
RLT	0.397	0.357	0.208	0.091	0.862		
SAI	0.165	0.142	0.386	0.494	0.134	0.815	
SER	0.343	0.327	0.26	0.067	0.327	0.205	0.83
HTMT							
	AT	CP	IC	OE	RLT	SAI	SER
AT							
CP	0.393						
IC	0.289	0.242					
OE	0.09	0.144	0.643				
RLT	0.45	0.399	0.219	0.091			
SAI	0.179	0.153	0.446	0.57	0.144		
SER	0.385	0.365	0.283	0.08	0.361	0.231	

Notes: EBSI = Effective Buyer–Seller Interaction; POSE = Performance of Sales Employees; SER = Sales Employee Retention; IC = Individual Characteristics; OE = Organisational Ecosystem; SAI = Social Affiliation and Integration; AT = Autonomy; CP = Competence; RLT = Relatedness; α = Cronbach's alpha; rho_A = Dijkstra–Henseler reliability; CR = Composite Reliability; AVE = Average Variance Extracted HTMT = Heterotrait–Monotrait ratio; β = standardised path coefficient; O = Original Sample; M = Sample Mean; STDEV = Standard Deviation; R^2 = explained variance; f^2 = effect size; Q^2 = predictive relevance; SRMR = Standardized Root Mean Square Residual; d_ULS = ULS discrepancy; d_G = geodesic discrepancy; NFI = Normed Fit Index; VIF = Variance Inflation Factor; PLS-SEM = Partial Least Squares SEM; SGI = Single Global Item.

Source: own research

Table 2 displays the outcomes of the discriminant validity evaluation employing the Fornell-Larcker criterion and the HTMT correlation ratio (Fornell & Larcker, 1981) assert that a construct must have greater variance with its indicators than with other constructs within the model. This criterion is satisfied when the square root of the AVE, the diagonal elements of the matrix, exceed the inter-construct correlations. In Table 2, the diagonal values for each construct surpass their correlations with other constructs, hence affirming discriminant validity. The HTMT ratio, a contemporary and rigorous approach introduced by (Henseler, Ringle & Sarstedt, 2015), further substantiates discriminant validity. All HTMT values are below the conservative criterion of 0.85, signifying that the conceptions are empirically distinct. The maximum HTMT value is 0.643 (between IC and OE), remaining within acceptable thresholds and further substantiating discriminant validity. The current study confirms that the conceptions are sufficiently diverse both theoretically and quantitatively. This distinction guarantees the precision of ensuing structural model estimations and enhances the validity of the theoretical

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2025 Volume 13 Number 2 (December)
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linkages examined in the research (Franke & Sarstedt, 2019). The Single Global Item (SGI) technique was utilised to assess the convergent validity of the formative higher-order constructs, as advised by Sarstedt et al. (2019) and Hair et al. (2021). Each construct, EBSI and POSE, was evaluated by a single reflecting item that encapsulated the overall perspective of the idea. The findings demonstrated robust and significant correlations: $\beta = .939$ for EBSI and $\beta = .924$ for POSE, thus affirming the convergent validity of the formative constructs.

4.2 Structural Model Evaluation and Mediation Analysis

The assessment of the structural model, relying exclusively on the supplied path coefficient tables, provides robust empirical evidence for the proposed linkages among EBSI, POSE, and SER. The direct impact of EBSI on POSE is positive and statistically significant, as evidenced by an original sample coefficient of 0.325, a t-statistic of 7.497, and a p-value of 0.000. This suggests that superior interactions between buyers and sellers markedly improve the performance of sales personnel. Within the framework of SDT, this relationship highlights that relational dynamics facilitate the satisfaction of psychological demands such as autonomy and competence, which are essential motivators of performance. The ties from EBSI to SER are noteworthy ($\beta = .192$, $t = 3.649$, $p < .001$), indicating that EBSI exerts a direct and beneficial influence on the retention of sales personnel. This suggests that when sales professionals engage in significant, courteous, and trust-based interactions with buyers, they are more likely to maintain their commitment to the firm. This relational feature cultivates a sense of social connection and acknowledgement, corresponding with the SDT requirement for relatedness. Moreover, POSE demonstrates a significant positive impact on SER ($\beta = 0.374$, $t = 7.222$, $p < .001$), suggesting that employees who view themselves as competent and motivated in their positions are more inclined to remain with their current business. This underscores the significance of performance not merely as a result of EBSI but also as a crucial precursor to retention. High-performing employees typically feel enhanced pleasure, engagement, and recognition, all of which contribute to extended organisational retention. The particular indirect impact was estimated to assess the mediating function of POSE in the connection between EBSI and SER. The findings demonstrate that EBSI substantially affects SER via POSE, exhibiting an indirect impact coefficient of 0.122, a t-statistic of 5.404, and a p-value of 0.000. This outcome provides unequivocal evidence of partial mediation, indicating that EBSI promotes retention both directly and indirectly by initially enhancing employee performance. This mediating effect aligns theoretically with SDT, wherein EBSI satisfy intrinsic motivational requirements, resulting in POSE, which then improves SER. This signifies those relational methods alone are insufficient for maximising retention; these strategies must enhance employee performance and motivation to effectuate enduring retention outcomes.

Table 3. Structural Paths with Hypotheses

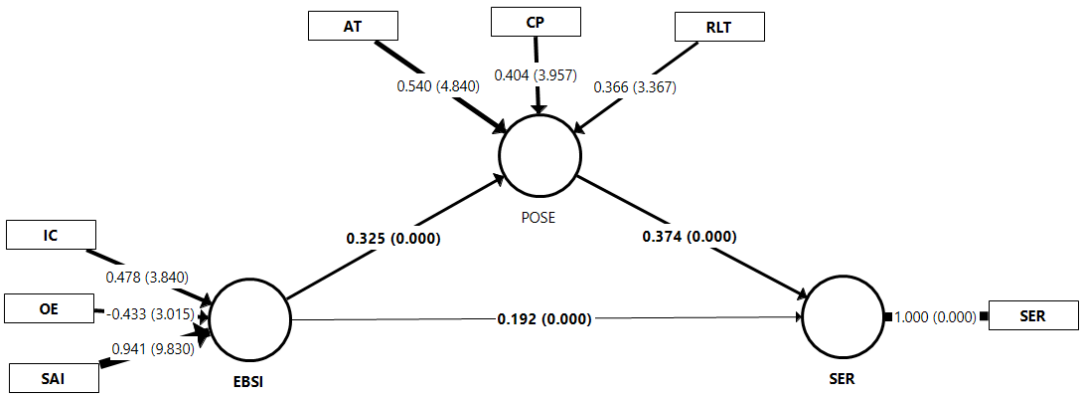
Path	Effect Type	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	*P*	Hypothesis
Path Coefficients							
EBSI → SER	Direct Effect	.192	.193	.053	3.649	.000	H_1
EBSI → POSE	Direct Effect	.325	.333	.043	7.497	.000	H_2
POSE → SER	Direct Effect	.374	.377	.052	7.222	.000	H_3
Specific Indirect Effect							
EBSI → POSE → SER	Indirect Effect	.122	.125	.023	5.404	.000	H_4
Total Effects							
EBSI → SER (Total)	Total Effect	.314	.318	.05	6.219	.000	$H_1 + H_4$

Notes: EBSI = Effective Buyer–Seller Interaction; POSE = Performance of Sales Employees; SER = Sales Employee Retention; IC = Individual Characteristics; OE = Organisational Ecosystem; SAI = Social Affiliation and Integration; AT = Autonomy; CP = Competence; RLT = Relatedness; α = Cronbach's alpha; rho_A = Dijkstra–Henseler reliability; CR = Composite Reliability; AVE = Average Variance Extracted HTMT = Heterotrait–Monotrait ratio; β = standardised path coefficient; O = Original Sample; M = Sample Mean; STDEV = Standard Deviation; R^2 = explained variance; f^2 = effect size; Q^2 = predictive relevance; SRMR = Standardized Root Mean Square Residual; d_ULS = ULS discrepancy; d_G = geodesic discrepancy; NFI = Normed Fit Index; VIF = Variance Inflation Factor; PLS-SEM = Partial Least Squares SEM; SGI = Single Global Item.

Source: own research

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2025 Volume 13 Number 2 (December)
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The cumulative impact of EBSI on SER is 0.314, comprising a direct effect of 0.192 and an indirect effect of 0.122 through POSE. This suggests that although EBSI directly aids retention, a significant part of its impact is achieved through performance improvement. The more substantial overall effect, in contrast to the direct impact alone, underscores the importance of employee performance as a vital conduit connecting relational contacts with enduring organisational commitment. The overall impact of POSE on SER is .374, aligning with its direct effect, as it does not function through an alternative mediator in this model. The robustness of this pathway underscores the significance of intrinsic motivational outcomes. Sales professionals who experience autonomy, competence, and social connectivity exhibit superior performance, and those with enhanced performance are more likely to remain with the firm for an extended period.



Notes: EBSI = Effective Buyer–Seller Interaction; POSE = Performance of Sales Employees; SER = Sales Employee Retention; IC = Individual Characteristics; OE = Organisational Ecosystem; SAI = Social Affiliation and Integration; AT = Autonomy; CP = Competence; RLT = Relatedness; α = Cronbach's alpha; rho_A = Dijkstra–Henseler reliability; CR = Composite Reliability; AVE = Average Variance Extracted HTMT = Heterotrait–Monotrait ratio; β = standardised path coefficient; O = Original Sample; M = Sample Mean; STDEV = Standard Deviation; R^2 = explained variance; f^2 = effect size; Q^2 = predictive relevance; SRMR = Standardized Root Mean Square Residual; d_ULS = ULS discrepancy; d_G = geodesic discrepancy; NFI = Normed Fit Index; VIF = Variance Inflation Factor; PLS-SEM = Partial Least Squares SEM; SGI = Single Global Item.

Figure 2. Structural Model

The analysis of the structural model, as illustrated by Table 3 and Figure 2, indicates that EBSI serves a dual function: it directly increases SER and indirectly enhances retention by elevating the POSE. The significance of POSE as a mediator underscores the critical importance of translating relational experiences into psychological and behavioural outcomes. The findings validate all hypothesised relationships (H1 to H4) and reinforce the theoretical framework of Self-Determination Theory, illustrating that relational quality, when aligned with the satisfaction of core psychological needs, significantly influences performance and retention in high-pressure sales environments.

The study's findings indicate that essential indicators, such as R^2, f^2, Q^2, and model fit indices, offer insights into the model's robustness and appropriateness within the PLS-SEM framework. The R^2 values indicate that the model accounts for 10.6% of the variance in POSE and 22.4% of the variance in SER. Although low, these values are permissible in behavioural research, particularly considering the intricacy of psychological notions. The f^2 results indicate that EBSI exerts a minor-to-moderate effect on POSE (.118), a negligible impact on SER (.042), and that POSE has a moderate effect on SER (.161). This confirms the role of POSE as a vital intermediary in linking buyer-seller interactions to employee retention. The Q^2 values obtained from blindfolding are .056 for POSE and .200 for SER, signifying minimal and moderate predictive relevance, respectively. EBSI has a Q^2 value of .000, as anticipated.

The model's fit indices further validate its resilience. The SRMR value of 0.017 is significantly below the 0.08 criterion, indicating an exceptional fit. Likewise, d_ULS (.008) and d_G (.003) are exceedingly low, indicating negligible misspecification. The Chi-square value (7.418) is minimal, and the Normed Fit Index (NFI) is .988, signifying a robust comparative fit. In conclusion, the model demonstrates a robust match along with sufficient explanatory and predictive capabilities. The combination of satisfactory R^2, large f^2, and Q^2 values, along with

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2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/y2734537888

superior fit indices, substantiates that EBSI has a significant effect on SER, particularly through its influence on POSE. These findings corroborate the theoretical framework based on Self-Determination Theory (SDT), underscoring the importance of promoting autonomy, competence, and relatedness to enhance performance and reduce turnover.

4.3 Discussion

The first hypothesis (H1) proposed that EBSI would have a positive influence on SER. The results confirmed this relationship ($\beta = 0.192$, $p < 0.001$), showing that relational quality directly supports retention. Consistent with prior studies (Zang et al., 2020; Canales-Ronda, 2024), trust, transparency, and mutual respect were identified as determinants of employee satisfaction and loyalty. EBSI fosters a work climate where employees feel valued and connected, fulfilling their psychological need for relatedness and enhancing organisational commitment. From an SIT perspective, IC, OE, and SAI strongly shaped EBSI, reinforcing identity alignment, belonging, and professional identification—key mechanisms that motivate retention in high-pressure sales contexts.

The second hypothesis (H2) predicted that EBSI would enhance employee performance. The findings supported this claim ($\beta = 0.325$, $p < 0.001$). High-quality client interactions increased intrinsic motivation by satisfying autonomy, competence, and relatedness needs as articulated by SDT. This finding aligns with prior research (Bjørnholt, Boye & Mikkelsen, 2022; Gilbert et al., 2022), which highlights that relational trust and positive customer feedback enhance self-efficacy, satisfaction, and engagement. Customer admiration and adaptive selling experiences served as motivational energy sources, elevating performance.

The third hypothesis (H3) examined the direct link between POSE and SER, which was strongly supported ($\beta = 0.374$, $p < 0.001$). This reinforces evidence that high-performing employees are more satisfied, engaged, and aligned with organisational goals, making them less likely to leave (Kakkar et al., 2020; Alsafadi & Altahat, 2021). Employees whose psychological needs are met tend to be more resilient, enthusiastic, and loyal.

The fourth hypothesis (H4) examined the mediating role of POSE in the relationship between EBSI and SER. The results confirmed partial mediation (indirect effect = 0.122, $p < 0.001$), indicating that while EBSI directly influences retention, its more substantial effect emerges through improvements in employee performance. This finding extends SDT-based research by demonstrating that relational quality promotes psychological fulfilment, which in turn drives sustainable workplace outcomes (Good et al., 2020; Ghani et al., 2022).

From a behavioural sciences perspective, these findings confirm that workplace interactions are not merely transactional but profoundly psychological. Employees who experience trust, autonomy, competence, and relatedness are more intrinsically motivated, perform at higher levels, and are less inclined to leave their organisations. The mediating role of performance demonstrates that external job conditions do not simply determine retention, but how social interactions foster psychological fulfilment and identity integration.

Overall, this research advances both applied psychology and organisational behaviour by confirming that motivational and identity-based mechanisms explain why relationally intensive professions experience high turnover, and how organisations can address this issue. The study integrates relational selling with motivational theory, presenting a novel paradigm in which EBSI and POSE function as formative constructs shaped by psychological needs and identity cues, ultimately linking motivation to retention outcomes.

From a practical standpoint, banking managers should focus on recruiting and training for interpersonal skills, fostering organisational cultures that provide autonomy and feedback, and establishing recognition systems that build competence and connectedness. These initiatives strengthen performance while also enhancing long-term retention by aligning work environments with employees' intrinsic motivational needs.

Despite its contributions, this study faces several limitations. We analyse banks as sales-intensive service organisations; replication in non-bank sales settings is encouraged. Its focus on the Indian banking sector may restrict generalizability to other industries or cultural settings; future studies should test the model in retail, insurance, or technology contexts. The cross-sectional design limits causal inference, and longitudinal research

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2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/y2734537888

could better capture the dynamics of motivation and retention over time. Additionally, potential moderating factors, such as leadership style, organisational culture, or macroeconomic conditions, were not considered. Future research should incorporate these variables and adopt mixed-methods approaches to deepen understanding of how relational quality, performance, and retention interact across different professional settings.

4.4 Novelty & Implications

This research makes significant contributions to both theory and practice within the fields of sales management, organisational behaviour, and applied psychology. By integrating Effective Buyer–Seller Interaction (EBSI) and Performance of Sales Employees (POSE) with the frameworks of Self-Determination Theory (SDT) and Social Identity Theory (SIT), the study introduces a novel behavioural model that explains how psychological and relational dynamics shape employee performance and retention. This approach shifts attention away from purely transactional outcomes and emphasises the fulfilment of intrinsic motivational needs and identity alignment as central drivers of sustainable commitment.

Theoretical contributions: The study extends SDT and SIT into the domain of employee retention by demonstrating how autonomy, competence, and relatedness transform relational experiences into measurable organisational outcomes, and how individual characteristics, organisational ecosystems, and social affiliations reinforce effective buyer–seller interactions. In doing so, it advances a unified behavioural framework that connects motivation and identity with retention outcomes in relationally intensive professions.

Practical contributions: The findings offer actionable guidance for managers and human resource professionals in designing effective retention strategies and performance enhancement initiatives. Investments in interpersonal skill development, structured feedback systems that promote autonomy and competence, and recognition programs that foster relatedness can significantly improve employee motivation and loyalty. Additionally, cultivating a culture of inclusivity and belonging strengthens identity alignment, which in turn enhances relational quality and reduces turnover.

Cross-sector relevance: Although focused on the Indian banking sector, the study's insights extend beyond financial services to other relationship-driven professions, such as teaching, nursing, counselling, and social work, where retention challenges are similarly shaped by relational quality, motivational fulfilment, and identity-based factors.

By combining relational selling with motivational and identity-based theory, this research underscores the strategic importance of fostering high-quality social interactions and supportive organisational cultures as mechanisms for sustaining employee performance and retention in demanding professional contexts.

4.5 Limitations and Paths for Future Researchers

Nonetheless, the research possesses certain drawbacks. The parameters of the study are confined to sales professionals engaged in industries that are predominantly dependent on enduring buyer-seller relationships, such as the financial services industry, like banks. This geographic and industry-specific emphasis may influence the generalizability of the findings while simultaneously ensuring a contextually rich analysis. The limitation mentioned above could hinder the applicability of the results to different industries or cultural environments.

Conclusions

This study set out to elucidate the complex relationships among Effective Buyer–Seller Interaction (EBSI), Performance of Sales Employees (POSE), and Sales Employee Retention (SER) through the theoretical lenses of Self-Determination Theory (SDT) and Social Identity Theory (SIT). In the high-stakes environment of the Indian banking sector, the findings confirm that cultivating meaningful, trust-based buyer–seller relationships significantly enhance employee performance and fosters long-term retention.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
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Empirical results robustly support the proposed model: EBSI exerts a direct positive effect on both POSE and SER, while POSE partially mediates the relationship between EBSI and SER. These outcomes demonstrate that relational quality in sales contexts is not merely a transactional advantage but a strategic lever for stimulating intrinsic motivation, thereby elevating performance and reducing turnover. The effectiveness of sales employees thus emerges as both a product of strong relational practices and a critical determinant of retention.

By reframing employee retention as a behavioural science phenomenon, driven by interaction quality, motivational fulfilment, and social identity, the study advances a more holistic understanding of the socio-psychological mechanisms underpinning workforce stability. The integration of SIT and SDT highlights how identity alignment and psychological need satisfaction jointly shape sales employee motivation and commitment. Methodologically, the use of formative higher-order constructs (EBSI and POSE) provides an innovative approach for examining multidimensional behavioural constructs, offering richer insights into the relational and motivational foundations of retention.

Ultimately, this research demonstrates that fostering high-quality buyer–seller interactions not only strengthens employee engagement and performance but also secures workforce stability. By aligning organisational practices with the psychological needs and identity orientations of sales personnel, companies can transform routine customer interactions into enduring strategic value, thereby cultivating a resilient and high-performing sales force.

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MANAGEMENT IN REAL ESTATE: POWERED BY DIGITAL TWINS

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Abstract. The real estate industry, as a major contributor to global carbon emissions, is under intense pressure from investors and regulators to integrate environmental, social, and governance (ESG) criteria into its core strategy. However, managers of large, heterogeneous building asset portfolios commonly face a key challenge: how to make data-driven strategic decisions that enhance sustainability and energy performance in the absence of detailed operational data for most assets. Traditional ESG approaches often rely on static, variable-quality reports and lack the forward-looking, quantitative tools necessary for effective strategic decision-making and risk management. This paper aims to address this challenge by proposing and validating an innovative dynamic ESG management framework. The framework establishes a dynamic simulation environment by integrating Digital Twin (DT) and Deep Reinforcement Learning (DRL) technologies, aiming to enhance the dynamic capabilities of organisations for sustainable transformation systematically. Using 564 commercial buildings in Singapore as case studies, we conducted a multi-criteria scenario analysis of multiple Energy Conservation Measures (ECMs) to measure their combined impacts in terms of energy, cost, carbon emissions and occupant comfort. Findings show that the framework can provide decision support beyond traditional approaches, revealing non-intuitive management insights such as that reducing internal heat gain has a greater impact on total energy consumption than directly increasing heating, ventilation and air conditioning (HVAC) efficiency, and quantifying trade-offs between financial returns, carbon emission reductions and social outcomes (occupant comfort). The core contribution of this paper is that it demonstrates how cutting-edge digital technologies can be utilized to transform ESG management from a passive compliance reporting activity to a proactive, dynamic governance function centred on sense-capture-reconstruct, which managers can use to assess capital investments, validate sustainability paths, and effectively manage the This supports managers in evaluating capital investments, validating sustainability paths, and effectively managing the complex interplay between environmental, social, and financial performance.

Keywords: digital twin; ESG; building energy management; decision support; Singapore green building

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1. Introduction

1.1 Background

With the real estate industry accounting for approximately 39% of global carbon emissions, of which asset and property management processes alone account for 28%, the industry is under intense pressure to improve its sustainability, given the growing global focus on sustainability and carbon neutrality goals (Boland et al., 2022), for managers of large commercial real estate portfolios, environmental, social, and governance (ESG) has evolved from a fringe topic to a core driver of strategy and value creation in the real estate industry (Ghisellini et al., 2018; SSGA, 2025; SuMi TRUST, 2024; Di Liddo, 2025). Global ESG assets are expected to exceed $53 trillion by 2025, marking a fundamental shift in the market (ECOVIS, 2024). A combination of growing investor pressure drives this shift (Kastratović et al., 2024), tightening regulatory requirements (e.g., the EU's

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Corporate Sustainability Reporting Directive CSRD), and widespread market recognition of the intrinsic link between sustainability performance and long-term financial returns and risk mitigation (Shahid et al., 2024; Yang et al., 2024).

The real estate sector is in the spotlight due to its large environmental and social footprint. The sector will account for approximately 34% of global energy-related CO_2 emissions in 2023, as well as around 34% of total global demand for energy (Global Alliance for Buildings and Construction, 2025). Decarbonization of the built environment is therefore essential to promote sustainable development and achieve global climate goals, such as those outlined in the Paris Agreement (Falana et al., 2024; Van Tam et al., 2024; Sebbaghi et al., 2025).

In this context, 'Twin Transition' - the intertwined and synergistic process of digital and green transformation - has become the dominant paradigm for realising a sustainable and competitive future (Rehman et al., 2023; Burinskienė & Nalivaikė, 2024; Razminienė & Tvaronavičienė, 2024; Baumgartner et al., 2025). At its core lies the use of advanced digital technologies to facilitate the transformation to a circular economy (Ortega-Gras et al., 2021).

However, while the "what" of ESG integration is clear, the "how" is difficult in practice. The central challenge facing ESG management today is how to create a new framework that shifts the reliance on retrospective and often inconsistent ESG disclosures to credible, forward-looking strategic decision-making (Chopra et al., 2024). Managers generally lack quantitative tools that can reliably predict the aggregate future impact of today's capital decisions, leading to a significant "data-to-decision" gap (INREV, 2025). This is essentially a Strategic Foresight dilemma and reflects the common dilemma of companies building and adapting their organisational capabilities to meet grand challenges in a rapidly changing environment.

1.2 Literature review

ESG integration in the real estate industry faces multiple challenges. First, data quality and comparability are ongoing issues. While different rating agencies and reporting frameworks (e.g., GRESB, GRI) provide structure (Anders et al., 2025), differences in their methodologies lead to inconsistent ratings, making cross-asset and cross-market comparisons difficult (Gleeson-White, 2014; Chatterji et al., 2016; Berg et al., 2022). Second, the risk of "greenwashing" seriously erodes the trust of investors and stakeholders (Lashitew, 2021; Li et al., 2023; Mehmeti et al., 2024; Poiriazi et al., 2025). Under increasing pressure to report environmental impacts, some companies selectively disclose relatively benign impacts, creating an impression of transparency while obscuring their actual performance (Marquis et al., 2016). Companies may exaggerate their environmental performance by issuing vague or misleading statements, while the lack of verifiable forward-looking data makes these statements difficult to falsify (Yu et al., 2020; Pigatto et al., 2023; Dorfleitner & Utz, 2024; Jurgelāne-Kaldava et al., 2024). Finally, traditional ESG analysis is often static and isolated. Instead of accepting multiple perspectives, it often becomes one-sided and dominated by business case logic (Roszkowska-Menkes et al., 2024). It fails to fully capture the complex interactions between the three pillars of E, S, and G, and cannot provide adequate support for dynamic, long-term capital allocation decisions (INREV, 2025).

The "twin transformation" theory provides a conceptual framework for addressing the above challenges. The theory believes that digital transformation and green transformation are mutually synergistic and mutually reinforcing (Baumgartner et al., 2025; Schallmo et al., 2025). Digital technologies, particularly artificial intelligence (AI), the Internet of Things (IoT), and digital twins (DT), are viewed as fundamental enablers of sustainable development (Ortega-Gras et al., 2021; Askar et al., 2024). In the built environment, DT technologies bridge the data-to-decision gap by creating dynamic virtual replicas of physical assets, allowing managers to simulate, predict, and optimise in a risk-free environment (Kang & Mo et al., 2024; Ohueri et al., 2024).

Moreover, there are considerations related to human decision-making beyond the ESG framework. Human values have been shown to play a pivotal role in shaping decision-making across contexts, influencing individuals' willingness to take risks, adopt new behaviours, and engage in practices with broad societal implications. For example, a study in Latvia identified distinct value profiles between taxpayers and tax evaders: individuals who prioritised self-centred or ambitious values were significantly more inclined to evade taxes (a

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grey economy behaviour), whereas those endorsing values like inner harmony and tradition tended to view tax-paying as the socially proper course. Notably, the latter group also exhibited more sustainable consumer tendencies—over half reported choosing eco-friendly products, even at a premium price (53%, compared to 45% in the general population). This finding suggests that pro-social and transcendent values correlate with responsible, sustainability-oriented behaviours (Kaže, Škapars & Bolinskis, 2011). It highlights how underlying values can drive choices that impact social and environmental outcomes. Similarly, in the realm of regional development, aligning services with human values has been found to be critical (Kazieva, Große & Larsson, 2024).

Extending these insights to technological innovation, it becomes evident that the adoption of tools such as digital twins for sustainability-oriented projects is not determined solely by technical capability. Digital twin (DT) adoption and sustainable innovation may hinge on value alignment, user well-being, and cultural fit. Values constitute the "dominating force" behind human motivation; thus, an innovation that resonates with stakeholders' core values is more likely to be accepted and used effectively, whereas one that conflicts with or ignores those values may face resistance regardless of its touted benefits. In practice, this means that even a highly sophisticated DT solution must align with the beliefs and needs of its end-users and the broader community. If a community strongly values tradition or social cohesion, for example, they might be hesitant to embrace a new digital system unless it is framed and implemented in a way that respects and supports those values. Prior literature supports the importance of such alignment: understanding the value dispositions of target user groups allows for tailored communication and implementation strategies. Interventions (e.g., campaigns against tax evasion) are more effective when framed in terms of the values important to the audience, rather than purely utilitarian arguments. Thus, promoting digital twin initiatives in a manner that emphasises their consonance with local values (such as community empowerment, environmental stewardship, or economic security, depending on context) could be pivotal for encouraging uptake. Ultimately, bridging the gap between technical solutions and human values is essential for technology adoption that genuinely contributes to long-term well-being and sustainability. This is well-observed if values are studied by novel tools that exclude biases, e.g. image-based methods that are assisted by machine-learning (Kaže et al., 2022), which implicitly suggest that integrating advanced value assessment methods, like image-based tools, into the innovation process offers a promising pathway to ensure that digital twin technologies and other sustainable innovations resonate with end-users' values, thereby enhancing adoption and positive impact.

Building on these human-centric considerations, organisational readiness for digital transformation emerges as another critical enabler of sustainability-oriented innovation, including DT. It has been illustrated that leveraging e-environment tools (i.e., Internet-based platforms) yields significant benefits for sustainable business development. The study also found that many companies remain at only an initial stage of mastering such digital tools, underutilising even basic resources. This gap in digital literacy and e-readiness suggests that without a baseline of technological competence and awareness, firms may struggle to realise the full potential of advanced digital innovations (such as digital twin (DT) solutions) in driving sustainable development. In other words, organisational digital maturity – including up-to-date e-environment strategies – is a foundational precondition for translating technical capabilities into successful sustainability-oriented innovation.

Similarly, gaps in sustainability awareness among stakeholders can undermine the impact of digital transformation initiatives. The reports on Poland, Latvia and Japan suggest that, despite broad policy efforts, encompassing all pillars of sustainability, the general public's sustainability awareness and knowledge remain below the global average (Miszczak et al., 2024). Although gradual improvements have been observed, this persisting awareness deficit signals a risk factor that may limit stakeholder support for new technologies like DTs aimed at sustainability. These findings underscore the importance of strengthening both sustainability-oriented mindsets and digital competencies. By bridging such awareness and capability gaps, organisations create a foundation where digital transformation efforts – exemplified by DT adoption – are value-aligned and more likely to accelerate progress toward sustainable innovation and development goals.

Deep reinforcement learning (DRL), an advanced AI technology, has demonstrated significant potential in solving complex dynamic optimisation problems, such as HVAC control (Lazaridis et al., 2024; Liao et al., 2024). Compared with traditional rule-based or model-predictive control methods, DRL can autonomously learn

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adaptive strategies to achieve a better balance between energy efficiency and comfort management (Chowdhury et al., 2024). However, the application of DRL also faces challenges, such as inefficient training data and trust issues in the "black box" decision-making process. Combining DRL with high-fidelity DT provides an effective path to solve these problems (Bousnina & Guerassimoff, 2024; Hagström et al., 2025).

This study is based on this series of academic backgrounds. It aims to demonstrate, through a specific case, how a framework integrating PINN, DT, and DRL can systematically address the strategic foresight problems inherent in traditional ESG management.

1.3 Research Objectives and Framework

To bridge the "data-to-decision" gap, this paper proposes and validates a dynamic ESG management framework based on Digital Twin (DT) and Deep Reinforcement Learning (DRL) utilising digital twin technology. The framework aims to transform ESG from a static compliance reporting activity to a proactive, data-driven strategic management function.

The core research question of this paper is: how can a DT framework integrated with DRL provide forward-looking and strategically valuable decision support for decarbonization investments in commercial real estate through multi-criteria scenario analysis?

To answer this question, this paper will follow the IMRAD structure:

The "Methods" section will detail our approach to constructing the DT environment, training the DRL intelligences, and designing scenario analyses for the four ECMs, as well as presenting the experimental subjects and data. The "Results" section will present the quantitative results of the scenario analysis, including a decision matrix that integrates financial, environmental, and social benefits, as well as an analysis of 3D Pareto charts and sensitivity tornado diagrams. The "Discussion" section will provide insights into the managerial and sustainability implications of these results, particularly in relation to the dynamic capabilities framework of "sense-capture-reconfigure", exploring how it can reshape ESG governance, and discussing its limitations and future research directions.

2. Methods

The methodology of this study aims to develop a "cyber-physical vision engine" capable of forward-looking decision analysis and to utilise it as an experimental platform for testing dynamic capability theory. Here we dramatically simplify the technical process, focusing instead on the management functions and the value of decision support at each stage.

2.1 Phase 1: Building a High-Fidelity Digital Twin Environment

The basis of the analysis is a high-fidelity digital twin environment for building thermodynamics. We do not use pure white-box physics models (e.g., RC models), which are challenging to capture real-world complexity and lead to model mismatches. Instead, we employ the Physics-Informed Neural Network (PINN) technique. PINN makes it possible to fit the observed data while its output must obey the laws of physics by embedding the laws of physics (thermodynamic equations) as a soft constraint in the loss function of the neural network. This ensures that our digital twins are both physically interpretable and highly compatible with real data, providing a reliable "gym" for subsequent DRLagent training (Ohueri et al., 2024; Pomè & Signorini, 2024).

The following differential equations control the thermal dynamics of the building:

$$C, \frac{dT_{\text{in}}}{dt} = \frac{1}{R}(T_{\text{out}} - T_{\text{in}}) - \eta_u P_{\text{HVAC}} + Q_{\text{int}}$$

where C Is thermal capacitance, R is thermal resistance, T_{in}/T_{out} are indoor/outdoor temperatures, P_{HVAC} is HVAC power, η_u is a utility factor, and Q_{int} is internal heat gain.

The PINN is trained to minimise a composite loss function, $\mathcal{L}$, which includes both the data-fit error ($\mathcal{L}_{\text{data}}$,) and a penalty for violating the physical law, represented by the physics residual, $\mathcal{R}$:

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2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/h9697726695

$$\mathcal{R} = C\dot{T}_{in} - \frac{1}{R}(T_{out} - T_{in}) + \eta_u P_{HVAC} - Q_{int} \quad , \quad \mathcal{L} = \mathcal{L}_{data} + \lambda \|\mathcal{R}\|_2^2$$

Here, λ is a hyperparameter from 1→0.01, with a gradual decay. By penalising deviations from the physical equation, the network is forced to learn physically meaningful and generalizable parameters (R, C, η_u), creating a robust knowledge base for subsequent transfer.
From a management perspective, the core of this phase is to provide companies with a low-cost, risk-free "strategy sandbox". On this sandbox, managers can simulate the long-term consequences of different capital investment decisions, thus making invisible future risks (e.g., stranded assets) and opportunities (e.g., energy-saving potential) visible and quantifiable. This corresponds directly to the Dynamic Capability Theory's "Sensing" capability - the ability to recognise and assess opportunities and threats in the external environment.

2.1.2 Phase 2: Training and Evolving the DRL agent

We mapped the calibrated digital twin model to a building with only static metadata by transfer learning to map the dynamic laws to a building with only static metadata. We ultimately encapsulated the validated digital twin environment in combination with DRL into an OpenAI Gym-compliant BuildingEnv class, which is used as a high-fidelity simulation environment to train the Deep Reinforcement Learning (DRL) agent. To apply reinforcement learning, the building control problem is formalized as a Markov Decision Process (MDP), a mathematical framework for modeling decisions in environments where outcomes are partially stochastic and partially under the control of the decision maker. Its core components define the MDP:
State(s_t): agent-observable information, initially [indoor temperature, outdoor temperature, time vector].
Action(a_t): discrete control actions that the agent can take, i.e., nine different HVAC temperature setpoints.
Reward(rt): The objective function that guides the agent's learning is to minimise the weighted sum of energy consumption, comfort deviation, and control action changes. Our reward function is designed as a multi-objective cost function to be minimised, explicitly balancing environmental, economic, and social goals:

$$r_t = -(c_e P_t + c_d \max(0, P_t - P_{thr}) + c_c |T_{in} - T_{set}|)$$

where P_t is the energy consumption, T_{in} is the actual indoor temperature, and T_{set} is the chosen setpoint. The weighting coefficients c_e, c_d, and c_c allow for tuning the relative importance of each objective.

Subsequently, we used the Deep Q-Network (DQN) algorithm, a classical value function estimation algorithm in DRL for discrete action space problems (Chowdhury et al., 2024; Lazaridis et al., 2024; Liao et al., 2024). More importantly, to address the data asymmetry problem (i.e., a few buildings have detailed data, while most have sparse data) common in real estate portfolios, we employ a transfer learning approach. This approach allows us to extend the dynamics and control strategies learned from a single data-rich "source building" to a data-sparse "target building" at a very low marginal cost. This significantly enhances the scalability and real-world application value of the framework, addressing the major management challenge of scaling case-by-case insights into comprehensive portfolio strategies. This phase shifts from reactive forecasting to proactive optimisation, aimed at discovering the best operational strategies that can directly improve the sustainable performance of an asset, which constitutes an intelligent "refactoring" of existing operational routines.

2.1.3 Stage 3: Multi-criteria scenario analysis design

This is the core methodological phase of this study. We modelled and evaluated four hypothetical scenarios using the framework of Multi-Criteria Decision Analysis (MCDA) (Deda et al., 2025; Gaievskyi et al., 2025; Grondin et al., 2025), a structured decision support tool for evaluating alternatives between multiple, often conflicting, criteria (Mecca, 2023; Gaievskyi et al., 2025).

The four hypothetical scenarios are as follows:

1. DRL Control: Our final trained high-performance DRL agent is applied to the existing building, and its performance serves as a benchmark against which all hardware retrofit measures are compared.
2. LED Retrofit: Based on DRL Control, we simulate the effect of replacing conventional lighting with high-efficiency LED lighting systems. The benefits are split into two components:

Direct Lighting Savings: Engineering estimate based on industry standard (10.5 kWh/m²/year).

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2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/h9697726695

Indirect HVAC Savings: Based on the industry standard engineering methodology of "for every 3 kWh of lighting savings, an additional 1 kWh of air conditioning savings".
3. Chiller Upgrade (HVAC COP Upgrade): Simulates the effect of replacing a high-efficiency chiller by increasing the HVAC efficiency parameter eta by 20% in a simulated environment, based on DRL control.
4. Solar PV: Based on DRL control, analyse the effect of installing 50kWp PV panels to offset grid electricity consumption. The annual energy production is calculated using industry-standard engineering calculations based on annual average peak sunshine hours (PSH) and system performance ratio (PR).

Evaluation criteria include: (1) Financial metrics: annual electricity savings (GWh), estimated total investment (SGD), simple payback (years); (2) Environmental indicators: annual carbon emission reduction (t-CO_2); (3) Social indicator: annual social benefit (SGD), calculated by annual carbon emission reduction × social cost of carbon (SCC). We use a widely cited estimate based on international studies, which is 243.20 SGD/tCO_2, derived from an interagency working group led by the U.S. Environmental Protection Agency (EPA). According to the EPA's latest report, its recommended central estimate (at a 3% discount rate) is about \$190/tCO_2 (in 2022 dollars) (U.S. Environmental Protection Agency, 2022; Howard & Sylvan, 2024; Ashenfarb & Kotchen, 2025; Prest & Rennert, 2025).

All energy consumption results based on short-term simulations (1461 hours) were calibrated using an annualization factor (8760/1461 ≈ 6.0) to ensure that all analyses were performed at an annual scale. This process embodies the complete closed-loop application of digital twin technology in building energy management, from understanding the current situation to predicting the future, optimising operations, and assisting in decision-making, thereby giving it the attributes of being data-driven, seamlessly interactive, and featuring closed-loop feedback.

2.2 Data and Cases

To validate the utility and effectiveness of the framework, this study applies it to a real dataset in Singapore. Singapore presents a unique and compelling context for this research. As a densely populated, highly urbanised island nation, it faces significant pressure to manage its resources efficiently and mitigate its environmental impact. In response, the government has launched the Singapore Green Plan 2030, a comprehensive national agenda that outlines ambitious targets for sustainable development, including stringent goals for greening the building stock. This makes Singapore a "living laboratory" for testing and deploying innovative solutions that aim to achieve urban sustainability.

This study utilises a rich dataset from the Building and Construction Authority (BCA), Energy Market Authority (EMA), and Meteorological Service Singapore (MSS), covering 564 commercial buildings in Singapore from 2017 to 2020, including office buildings, retail spaces, and hotels. A rich dataset from BCA, Energy Market Authority (EMA) and Meteorological Service Singapore (MSS), covering 564 commercial buildings in Singapore from 2017 to 2020, including offices, retail spaces and hotels. The data sources are diverse, encompassing both static metadata and dynamic time-series data. Among them, Harbourfront Centre is the benchmark building, and its highly granular data can be used to build benchmarking models and generalise insights from a single source asset through migration learning to create physically-based energy performance benchmarks for each of the remaining buildings. This data structure (one building with exhaustive data and the remaining buildings with sparse data) perfectly models the real-world data asymmetry challenge that the framework aims to address. Table 1 provides the architecture of the available data. Each data point is not just a technical input, but a key indicator for sustainability assessment.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/h9697726695

Table 1. Data Schema and Availability Across Building Portfolio

Category	Field Name	Description	Data Availability	Time Granularity
Universal Dynamic Data	Outdoor Temperature (Tout)	Ambient air temperature	All 564 Buildings	Daily (2017–2020)
	Grid Emission Factor (GEF)	Carbon intensity of the electricity grid	All 564 Buildings	Daily (2017–2020)
	Electricity Tariff	Cost of electricity	All 564 Buildings	Daily (2017–2020)
Source-Specific Dynamic Data	Cooling Electrical Power (PHVAC)	Power consumed by the HVAC system	Source Building	Daily (2017–2020)
	Indoor Temperature (Tin)	Average internal building temperature	Source Building	Daily (2017–2020)
Universal Static Metadata	Green Mark Rating/Year	Building sustainability certification	All 564 Buildings	Single Point
	Gross Floor Area (GFA)	Total floor area of the building	All 564 Buildings	Single Point
	% Air-Conditioned Area (%AC)	Percentage of GFA that is cooled	All 564 Buildings	Single Point
	LED Penetration (%LED)	Percentage of lighting that is LED	All 564 Buildings	Single Point
	Chiller COP	Coefficient of Performance of the chiller plant	All 564 Buildings	Single Point
	Occupancy	Typical occupancy level or pattern	All 564 Buildings	Single Point
	PV Flag	Presence of photovoltaic systems	All 564 Buildings	Single Point
	System Type	Type of HVAC system installed	All 564 Buildings	Single Point
	Geographical coordinates	latitude/longitude	530 Building	Single Point
	Building Size	Large or Small	532 Building	Single Point
	Main building functions	Office Hotel Retail	522 Building	Single Point

Source: Singapore *BCA, EMA, & MSS*

In terms of experimental setup, this study uses data from 2017 to 2019 for model training. We selected data from a normal year (2018) and an abnormal epidemic year (2020) as a cross-test set to evaluate the final performance and generalisation ability of the model. This design was intentional. Tools used for long-term sustainability planning and investment must be robust and reliable. We explicitly stress-tested the resilience of the framework by testing it against the "black swan" event of the COVID-19 outbreak, which led to significant conceptual drift in energy use patterns. A model that can maintain predictive accuracy under such volatile conditions will be even more trustworthy as a basis for making multimillion-dollar investment decisions to achieve long-term sustainability goals.

Table 2. Baseline model performance assessment

Model	RMSE($kWh \cdot m - 2 \cdot yr$)	R^2
Persistence model	67.59	0.8680
Mean model	74.68	0.8388
Differential persistence model	79.57	0.8170

We then built a simple baseline model for the 522 heterogeneous data, and the results, as shown in Table 2, show that the simplest persistence model (i.e., predicting that the following year's EUI is equal to the previous year's EUI) performs the best, achieving surprisingly high performance on the test set. Its Root Mean Square Error (RMSE) is 67.59 kWh-m-^{2}-yr, and the coefficient of determination (R^2) is as high as 0.8680.

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2025 Volume 13 Number 2 (December)
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In this study, HarbourFront Centre in Singapore is selected as the source domain building. At the same time, based on the statistical analysis of the data showed that 2020 was an abnormal data year, the experimental scheme of Benchmark HarbourFront Centr digital twin was trained on the existing data with a strict time segmentation, using the 2017-2019 data as the training set, the 2018-Q1 and 2020 datasets were normalized to validate the epidemic validation, to realize the normalized + epidemic dual validation method.

The final Benchmark parameters obtained are $R = 5.02°C - day/kWh$, $C = 2.04kWh/°C$, η=0.704 (see Table 3).

Table 3. Benchmark parameters

Parameter	Numeric value	Typical range	Evaluate
R	5.02 °C·day/kWh	2 – 10	Normal
C	2.04 kWh/°C	1 – 5	Normal
η	0.704	0.6 – 0.9	Normal

Meanwhile, the normality validation, epidemic validation, and the training set are all in line with the engineering accuracy of the grey-box model.

3. Results

Based on the above data, we validated the model and trained a practical intelligence, which was applied to scenario simulation and analysis. We then aggregated the core quantitative results into a comprehensive investment decision and policy priority matrix, visualised and presented through 3D Pareto plots and sensitivity Tornado plots.

3.1 DRL agent learning results and model validation

Figure 1 illustrates the reward performance of the DRL agent over 500 rounds, from which we can see that at the beginning of training (Episode 10), the average score was -2554. As the training progressed, the average score steadily increased. By the end of training (Episode 500), the average score reaches -1171. The continuous increase in the score clearly indicates that the DRL agent is learning effectively. It is gradually finding control strategies that reduce the total cost (energy + discomfort + control changes) by interacting with the environment (Figure 1).

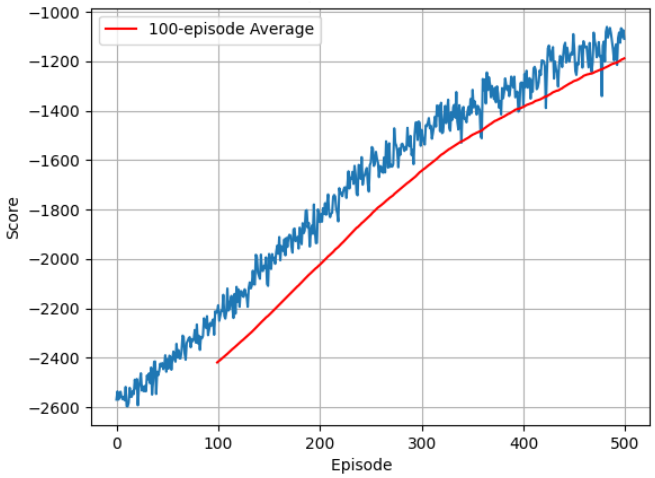


Figure 1. Changes in total rewards for intelligent body learning

After a series of systematic and targeted iterative optimisations, a high-performance DRL agent was successfully obtained. A 47.14% HVAC control energy saving rate was achieved in a trusted digital twin environment calibrated by a physical model, providing solid data support for its application in real buildings.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/h9697726695

More importantly, this significant energy saving result was achieved under the premise of strictly ensuring the comfort of indoor occupants, and the total comfort deviation was controlled at an extremely low level (29.13 °C·h) (see Table 4).

Table 4. Performance comparison of DRL agent and baseline policy

Metric	DRL Agent	Baseline (24°C)
Total energy (kWh)	707.45	1338.42
Total Comfort Deviation (°C·h)	29.13	0.00
Energy savings	47.14%	/
Total Reward	-860.54	1338.42
Action Change Cost	24.75	0.00

It can be seen that the agent has excellent predictive ability and balanced decision-making ability, which fully demonstrates the great potential and value of this technical route in the field of sustainable real estate management.

3.2 Integrated Decision and Policy Prioritisation Matrix

This study assumes a total annual energy consumption of 31,307.84 megawatt-hours (MWh) for the base building in FY2020 as the baseline value for the subsequent calculation of the total energy saving rate, assuming a total gross floor area (GFA) of 169,727 square meters (m2), and sets the Social Cost of Carbon (SCC) at SGD 243.20 per ton of CO_2 (SGD/tCO_2) (Table 5).

Table 5. TOPSIS Energy Saving Potential Ranking Table

ECM Scenarios	Building-wide Annual Energy Savings (%)	Building-wide Annual Energy Savings (GWh)	Building-wide Annual Carbon Reductions (t-CO_2)	Estimated Total Investment (SGD)	Building-wide Simple Payback Cycle (Years)	Societal Benefits (via SCC, SGD)	Policy Prioritisation (TOPSIS)
DRL Control Strategy	1.23%	0.39	157.51	~0 (software cost)	< 1	38,300	Base
Install PV panels	0.21%	0.07	26.74	75,000	3.83	6,503	High
LED lighting retrofit	7.59%	2.38	967.10	7,637,715	10.77	235,213	High
Increase chiller COP	< 0.01%	< 0.001	0.23	5,100,000	29,806.11	56	Low

The energy savings for “Installation of Photovoltaic Panels”, “LED Lighting Retrofit”, and “Increase in Chiller COP” in Table 5 represent incremental benefits resulting from the implementation of the “DRL Control Strategy”. DRL control strategy".

ENTREPRENEURSHIP AND SUSTAINABILITY ISSUES
ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/h9697726695

3.3 Visualisation and analysis

3.3.1 3D Pareto chart: finding the optimal decision frontier

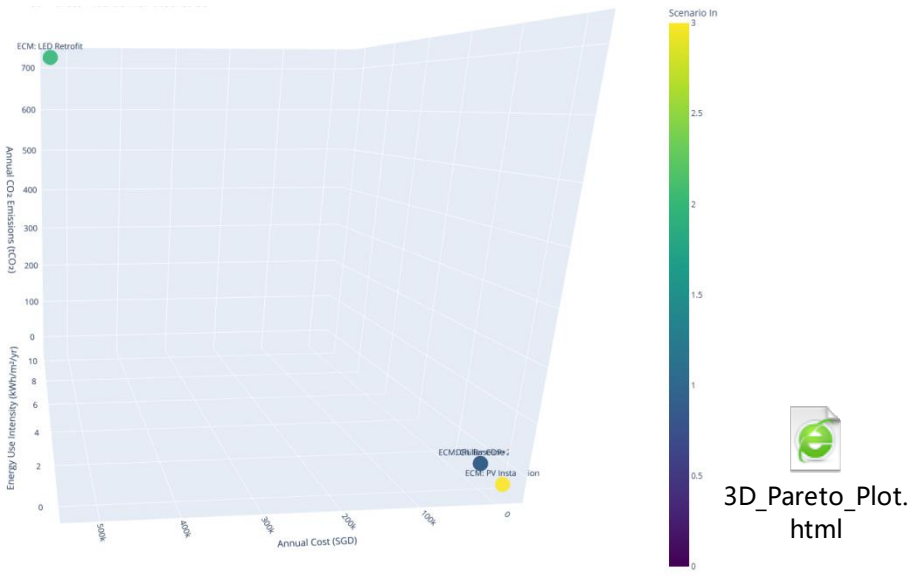


Figure 2. 3D Pareto chart

The 3D Pareto diagram visualises the combined performance of the scenarios in three dimensions: energy intensity (EUI), annualised costs, and annualised carbon emissions. The ideal scenario is as close as possible to the origin of the coordinate system (see Figure 2 above).

In the decision analysis of the scenarios, the option “Increase chiller COP” almost coincides with the DRL Benchmark, indicating that after Deep Reinforcement Learning (DRL) optimisation, the marginal benefit is almost zero. The marginal benefit is almost zero, so other, better options have fully outperformed it and can be considered an ineffective option with an insufficient return on investment.

Meanwhile, LED Retrofit and Photovoltaic Installation constitute the Pareto-optimal frontier for decision making, implying that there is no absolute advantage or disadvantage in all evaluation indicators. There is no absolute advantage or disadvantage, but rather a trade-off between the two - the former being the most significant in terms of reducing overall energy consumption, and the latter having a greater advantage in terms of speed of financial return.

3.3.2 Sensitivity Tornado diagrams: identifying key drivers

The sensitivity analysis quantifies the influence of key building parameters on the total energy consumption through Tornado plots, with Internal Heat Gain identified as the most sensitive leveraged variable, contributing most significantly to the energy consumption of the HVAC system; this finding explains the significant indirect energy savings from the LED retrofit in terms of reducing the heat dissipation of the lighting from the physical mechanism.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
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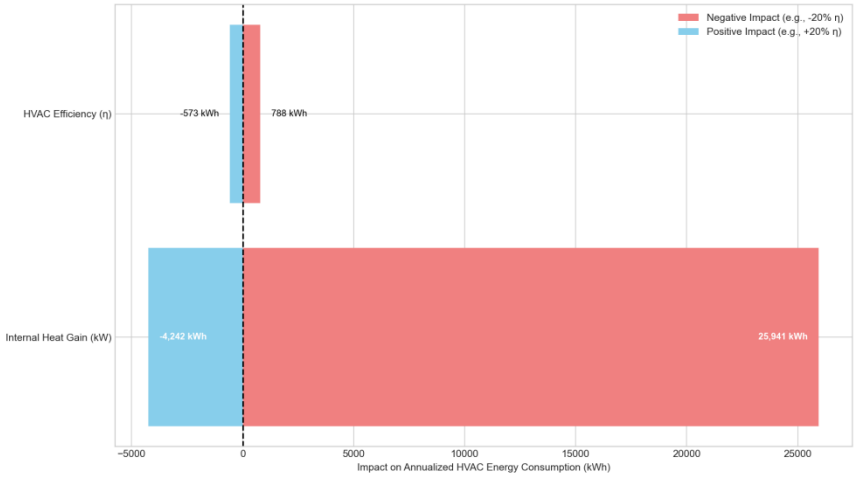


Figure 3. Sensitivity Analysis Tornado Plot

In contrast, the energy efficiency (ηThe performance of the HVAC equipment also shows some sensitivity (Figure 3). However, its influence is significantly smaller than that of the internal heat source, which further confirms that there is limited scope for additional energy savings by simply improving the efficiency of the hardware itself after Deep Reinforcement Learning (DRL) optimisation has already achieved an increase in operational efficiency.

4. Discussion

The findings of this study not only provide a basis for specific investment decisions but, more importantly, provide profound inspiration for the ESG management paradigm and sustainable development strategy of the real estate industry. We will systematically explain how this framework transforms ESG from a compliance burden into a dynamic governance capability that creates value, centring on the "sense-capture-reconstruct" syllogism of dynamic capability theory.

4.1 Sensing: Using digital twins to gain insight into future risks and opportunities

The dynamic capability theory defines "sensing" as the ability to identify and assess opportunities and threats in the external environment. In traditional ESG management, this "sensing" ability is severely limited due to the lack of forward-looking tools and metrics. Our framework gives managers a digital "sensing" ability through a simulation environment based on digital twins.

It allows managers to conduct "what-if" analysis of different energy-saving investment measures (ECMs) in a risk-free virtual space, thereby "sensing" the comprehensive impact of different capital decisions on dimensions such as energy, cost, carbon emissions, and comfort in the future. For example, managers can foresee that a costly chiller upgrade will become an investment with little return after the AI agent optimises operations, effectively avoiding the risk of "stranded assets" that may result from climate transition. This capability enables companies to go beyond the limitations of historical data and gain insight into the future state of their assets under various strategic paths, thereby actively shaping their environment rather than passively adapting to it.

4.2 Seizing: Seizing Value through a Data-Driven Framework

The "seizing" capability refers to the action of mobilising and allocating resources to capitalise on opportunities and create value. If "perception" is seeing the future, then "seizing" is making choices to achieve the optimal future. The multi-criteria decision analysis (MCDA), Pareto frontier diagrams, and TOPSIS rankings in this article are the decision-making mechanisms for "capturing" value.

They provide a structured, data-driven basis for capital allocation, helping managers make trade-offs between multiple (sometimes conflicting) goals. For example, based on the analysis results in Table 5 and Figure 2,

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2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/h9697726695

decision makers can clearly see that although the total energy saving effect of the photovoltaic project is limited, it has the fastest financial return (3.83 years' payback period). In comparison, the LED transformation project has a significant initial investment and a long payback period (10.77 years). However, its total energy saving potential and social benefits (measured by SCC) are the highest among all options. This quantitative trade-off analysis enables managers to effectively "orchestrate" corporate resources and make the most favourable investment decisions based on their own strategic priorities (for example, whether to prioritise short-term cash flow or long-term social impact).

4.3 Transforming: Reinventing assets and routines for long-term resilience

The ability to "transform" refers to the ability to continuously update and transform the organisation's asset base and operating routines to maintain competitiveness. This framework promotes "transforming" at two levels.
At the micro level, the AI agent itself is a "reconstruction" of operating routines. It replaces the traditional, static rule-based HVAC control model with an adaptive, continuously learning dynamic optimisation model, which is a manifestation of organisational learning and adaptation at the operational level. At the macro level, the entire framework prompts companies to "reconstruct" their capital investment strategies. It encourages companies to shift from a logic of solely pursuing short-term financial returns to a more resilient, long-term value creation logic based on ESG multi-dimensional goals. For example, by introducing the "social cost of carbon" (SCC) and incorporating social benefits into the TOPSIS ranking, the framework guides decision makers to internalise externalities, which is a key step in "reconstructing" sustainable business models.

4.4 Transforming ESG from compliance reporting to dynamic governance

The core contribution of the DT-DRL framework proposed in this study is to transform ESG management from a passive, retrospective reporting activity to a proactive, forward-looking dynamic governance mechanism.

1) Governance “E” Dimension: Verifiable Decarbonization Path: Under increasing pressure to report environmental impacts, some companies selectively disclose relatively benign impacts to create the impression of transparency while hiding their actual performance. Traditional ESG reporting is often criticised for “greenwashing” due to its static and retrospective nature (Marquis et al., 2016; Poiriazi et al., 2025). Our framework offers a scientific and auditable methodology for ex-ante assessment and validation of decarbonization pathways, directly responding to market demand for transparency and credibility (Cojoianu et al., 2024). It enables companies to confidently set and communicate their Science-Based Targets (SBTs) (Pinkse et al., 2023).

2) Governance of the ‘S’ dimension: quantifying human-centred values: The reward function of the DRL agent is a concrete operational tool for realising the governance of the social dimension. It transforms occupant comfort, a key social (S) metric, from a vague concept into a quantifiable, optimizable, and trade-offable operational parameter. This enables managers to explicitly manage and safeguard occupant well-being while pursuing cost-effectiveness, thereby enhancing the social value of the asset (American Assets Trust, Inc., 2024; Sekisui House Reit, Inc., 2024).

3) Governance “G” Dimension: Managing Stranded Asset Risks: Our analysis clearly identifies “upgrading chiller COP” as an ineffective investment. This is the core value of the framework as a risk management tool - avoiding Stranded Asset Risk due to the climate transition (Allianz, 2025; European Commission, 2025). Under increasingly stringent building energy efficiency regulations (e.g., EU EPBD) (European Commission, 2024; Shahid et al., 2024), inefficient assets are at significant risk of depreciation. Our framework improves the performance of existing assets at a fraction of the cost through “software over hardware” optimisation, effectively avoiding significant capital mismatches that could quickly “run aground”. This provides strong decision support for boards and management to fulfil their fiduciary responsibilities in an era of climate risk (ICG, 2025; Lazard Asset Management, 2024).

4.5 The “social cost of carbon” and policy priorities

To elevate the analysis of this study to a strategic level, we introduced the Social Cost of Carbon (SCC) as a measurement tool, which is defined as the long-term economic loss to society per unit of CO_2 emissions (Ashenfarb & Kotchen, 2025; Howard & Sylvan, 2024; Prest & Rennert, 2025). With the help of the SCC value (243.20 SGD/tCO_2), the corresponding societal benefit (SGD) can be calculated by multiplying the annual carbon emission reduction (tons of CO_2) of each measure by this cost factor. On this basis, we adopted the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method to rank the policy options

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/h9697726695

comprehensively. This method measures the relationship between each option and the "optimal ideal solution" (i.e., the solution with the shortest payback period and the best social benefits). The method prioritises the policy options by measuring their distance from the "optimal ideal solution", i.e. the one with the shortest payback period and the highest social benefits. The results show that PV module installation is closest to the "shortest payback" ideal, and LED lighting retrofit is closest to the "highest social benefit" ideal, thus both are rated as "high" priority; in contrast, LED lighting retrofits are rated as 'high' priority; in contrast, LED lighting retrofits are rated as "high" priority. "In contrast, upgrading the chiller COP was the furthest away from the ideal solution in terms of both payback period and social benefits, and was therefore rated as a "low" priority.

4.6 Managerial and Policy Implications

The results of this study provide targeted strategic recommendations for various types of decision-makers. For private sector investors, the deployment of intelligent control technologies such as Deep Reinforcement Learning (DRL) should be prioritized as a first investment area, as it maximizes the operational performance of existing assets at a low marginal cost; based on this, it is recommended to prioritize the installation of photovoltaic (PV) modules that have a short payback period and a quick payback in cash flow; In contrast, measures such as LED lighting retrofits, which have significant social benefits but relatively long private payback periods, should be incorporated into medium- and long-term capital renewal planning. On this basis, it is recommended that priority be given to PV module installation projects with short payback periods and quick cash flow returns. In contrast, measures with relatively long private payback periods despite their significant social benefits, such as LED lighting retrofits, should be included in medium- and long-term capital renewal planning and various external incentives should be actively pursued to enhance their investment attractiveness. For public policymakers, this study identifies a gap between the high social benefits and long private payback periods for LED lighting retrofits, providing an ideal entry point for incentive policies. Through mechanisms such as green building subsidies and tax credits, this benefit-payback gap can be effectively bridged to promote socially optimal solutions. At the same time, the promotion of Just Transition should be at the core of the policy, i.e., ensuring a fair distribution of costs and benefits during the promotion of energy efficiency retrofits to avoid disproportionate burdens on low-income groups and SMEs (Hughes & Hoffmann, 2020; Johnston, 2025), e.g., by setting up a special fund to support In addition, the government should strongly encourage enterprises to invest in software-defined technologies such as DRL intelligent control through financial and policy support, as they are one of the cost-effective paths to achieve the national goal of "carbon neutrality".

4.7 Implications for organisational learning and digital transformation

The contribution of this study extends beyond the expansion of dynamic capability theory, also providing important implications for digital transformation and organisational learning within organisations. Digital transformation is not simply a technological integration, but a profound organisational learning process; in this process, the digital twin-deep reinforcement learning framework proposed in this study can be regarded as an "organisational learning engine". First, by viewing building operations as complex adaptive systems, the framework guides managers to adopt systematic thinking and gain a deep understanding of the mutual coupling and feedback mechanisms between subsystems, such as lighting and HVAC, thereby achieving overall optimal decision-making under multi-objective trade-offs. Second, digital twins provide managers with a low-risk, high-fidelity virtual experimental field, encouraging them to quickly iterate and verify cutting-edge or even disruptive operational strategies in a simulated environment, thereby cultivating an innovative culture that advocates experimentation, tolerance and learning from failure. Ultimately, the framework quantifies the typically abstract ESG goals into measurable performance indicators. It combines deep reinforcement learning to generate optimal strategies in real-time, fundamentally promoting the decision-making paradigm from experience-driven to data-driven and evidence-based. This series of mechanisms jointly promotes the learning ability, innovative mindset and data culture required for the digital transformation of organisations, and provides a reference path and theoretical support for the digital practices of the construction industry and broader enterprises.

4.8 Limitations and directions for future research

Although this study has achieved significant results in operational carbon optimisation, several limitations still need to be addressed and improved upon in future studies. First, this study primarily focuses on operational carbon emissions. In contrast, the proportion of Embodied Carbon (EC) in total life cycle carbon emissions is becoming increasingly prominent with the continuous improvement of building energy efficiency (Terán-

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Cuadrado et al., 2024). Therefore, subsequent studies should incorporate Life Cycle Assessment (LCA) data into the Digital Twin (DT) framework to achieve comprehensive optimisation of carbon emissions over the whole life cycle of a building. Additionally, this study focuses on a single building as its object of analysis. In contrast, in practical applications, decision-makers often need to manage and optimise their entire real estate portfolio dynamically. Future work should integrate the DTDRL method more deeply with spatio-temporal models, such as the SpatioTemporal Graph Convolutional Network (ST-GCN), to achieve Environmental, Social, and Governance (ESG) objectives at a more macro scale.

On the other hand, deep reinforcement learning models are often regarded as "black boxes" in the control strategy generation process, and their decision logic lacks transparency, which limits their generalisation to high-risk financial and operational scenarios (Haghighat et al., 2025; ITSM GOAL, 2025; Perera et al., 2025). To this end, there is an urgent need for future research to integrate Explainable AI (XAI) techniques to reveal the core decision rules underlying the DRL Agent's energy consumption control process in order to build a foundation of trust, facilitate human-machine collaboration, and meet the increasingly stringent requirements for regulatory interpretability (Lakshmi et al., 2024; Siu et al., 2025).

Conclusions

In today's property and sustainability management, digital twins combined with deep reinforcement learning (DRL) methods represent a game-changer that can dramatically change the way we manage energy consumption, capital expenditures, and achieve ESG goals. The results of this study demonstrate that the integration of digital twins and intelligent algorithms opens up a new level of organisational management, transforming it from a traditional reactive model to a proactive, dynamic, and data-driven process:

1. Digital twins as a driver of organisational learning and decision making. One of the key advances is that digital twins provide managers with a virtual environment in which to simulate and evaluate the impact of various investment and operational decisions without risking tangible assets. This allows them to "feel" the future, predicting the impact of energy conservation and decarbonization measures on energy consumption, costs, carbon emissions, and user comfort. This capability fundamentally changes the role of the manager: from an executor of prescriptions, he or she becomes an active strategic player, capable of systematically analysing complex relationships and trade-offs between various performance indicators. Virtual experiments and scenario modelling stimulate innovative thinking and a culture of learning from mistakes, which contributes to the development of adaptability and resilience of the organisation in a rapidly changing external environment.

2. Deep reinforcement learning (DRL) as a tool for improving operational efficiency. The use of DRL enables you to continuously optimise the management of HVAC systems and other energy-intensive building subsystems, adapting to changing operating conditions. This increases operational efficiency without the need for large capital expenditures, which is especially important in conditions of limited resources and high sustainability requirements. The integration of DRL with digital twins creates a dynamic management model that not only enhances the current state of assets but also lays the groundwork for the long-term transformation of business models. This approach facilitates the transition from short-term financial return maximisation to multidimensional cost management, taking into account environmental, social, and governance factors.

3. Capital Investment Management: Trade-offs and Priorities Based on Data. An important element of the study is the use of multi-criteria analysis (MCA), specifically Pareto and TOPSIS methods, to develop sound investment priorities. Based on a quantitative assessment of the trade-offs between payback period, energy savings and the social cost of carbon (SCC), managers receive structured recommendations for capital allocation. For example, photovoltaic module installation projects demonstrate a quick payback and high financial attractiveness, which makes them a priority for short-term investments. At the same time, LED lighting retrofits, despite a more extended payback period, provide significant social and environmental benefits, which justify their inclusion in medium- and long-term strategic planning. This approach facilitates the transition from intuitive or one-sided decisions to transparent and informed investment management, taking into account sustainability - a key challenge for modern management.

4. Risk management and prevention of ineffective investments. The results show that investments in refrigeration equipment modernisation following the application of DRL optimisation are ineffective in terms of both ROI and social benefits. This highlights the importance of using digital twins and intelligent models to identify and prevent the risk of "stranded assets", especially in the context of increasing climate regulation and stricter regulations. Thus, digital technologies and advanced analytics become integral tools of the fiduciary duties of managers and boards of directors, helping to minimise financial and environmental risks.

5. Strategic importance for ESG and digital transformation. A systematic approach implemented through digital twins and DRLs facilitates the transformation of ESG management from static and retrospective reporting to a dynamic management function. This allows not only for measuring and controlling environmental indicators, but also for quantitatively integrating social and management parameters into the decision-making process. Of particular importance is the translation of social value, for example, the comfort of residents, from an abstract concept into a measurable operational parameter, which makes it possible to purposefully manage the social component and create additional value for the business. This integrated approach fosters organisational learning, innovation, and a data-driven culture, which forms the foundation for sustainable digital transformation and long-term competitiveness within organisations.

Limitations and Future Research

Despite the successes, the current research is limited by its narrow focus on operational emissions and the analysis of individual buildings. Future work requires expanding the models to account for the carbon footprint throughout the lifecycle and scaling the solutions to a portfolio of buildings. Additionally, the development of explainable XAI methods to enhance transparency and trust in the decisions made by DRL agents is a crucial direction that will facilitate the integration of intelligent systems in high-risk and regulated areas.

Digital twins combined with deep reinforcement learning open new horizons for building management and sustainability. They enable managers to make informed, balanced decisions, optimise resource use, and mitigate risks, while fostering a culture of continuous learning and innovation. This synergistic approach is becoming a key driver of digital transformation, ensuring the long-term resilience of organisations in the face of global climate and ESG challenges.

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THE DIGITAL TRANSFORMATION AND THE INCLUSIVE ECONOMY: NAVIGATING THE RISKS*

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Abstract: The article examines the paradoxical relationship between the development of an inclusive economy and the emergence of digital neo-feudalism. While central bank digital currencies (CBDCs) and asset tokenisation are presented as instruments for enhancing financial inclusion, reducing transaction costs, and supporting social stability, they simultaneously create unprecedented opportunities for state and corporate control over economic activities and personal data. The research highlights the dual nature of digital financial innovations: on the one hand, they democratise access to financial services and stimulate the development of small and medium-sized businesses; on the other hand, they concentrate power in the hands of central banks and digital platforms, fostering new forms of dependence. The study employs theoretical and comparative analysis to show how the combination of state regulation, Big Data, and technological monopolies can reproduce hierarchical structures reminiscent of neo-feudalism in a digitalised society. The findings suggest that the path toward an inclusive economy requires critical attention to ethical and institutional safeguards to avoid the risks of digital authoritarianism and the privatisation of social control.

Keywords: inclusive economy; central bank digital currencies (CBDC); asset tokenization; financial inclusion; digital platforms; Big Data; digital authoritarianism; digital neo-feudalism

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JEL Classifications: L26, J24, M13, I21

1. Introduction

At present, more than one billion adults across the globe remain excluded from the formal financial system, without access to conventional banking services such as savings accounts, credit, loans, or insurance. Individuals marginalized in this way are compelled to function within a cash-based economy, heavily dependent on physical assets, highly vulnerable to financial shocks and instabilities, and deprived of opportunities for capital accumulation and wealth generation (de Moraes, Roquete & Gawryszewski, 2023; Kum et al., 2024). Many countries associate attempts to create an inclusive economy with the development of state digital currencies,

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thanks to which central banks, the issuers of these currencies, will be able to monitor and support the financial activities of clients. “An inclusive economy would help households to accumulate, hold, and pass on wealth to the next generation. One key component of this effort is sometimes known as “financial inclusion” providing people the means to access, use, and benefit from all financial services such as bank accounts, credit, insurance, retirement savings, and investment products” (Aspen Institute, 2023). Most importantly, central bank digital currencies (CBDCs) have the potential to facilitate the provision of public goods and enhance the efficiency of government service delivery. This includes, for example, government-to-citizen transfers such as social welfare payments (e.g., COVID-19 relief measures) as well as credit and subsidy schemes targeting smallholder farmers or small and medium-sized enterprises. Notably, in low-income countries, almost 35% of adults opened their first financial account in order to receive government transfers (TBI, 2022; Atlantic, 2023).

2. Literature review

The debate on the relationship between financial inclusion and the digital transformation of the economy is embedded in broader theoretical discussions on capitalism, digitalisation, and new forms of social hierarchy (Huang & Zhu, 2022; Shen et al., 2024; Xue et al., 2025).

Nick Srnicek (2021) conceptualises "platform capitalism" as the dominant mode of contemporary accumulation, where digital infrastructures, rather than traditional industrial production, become the primary source of value extraction. Within this paradigm, inclusive economic policies - while aimed at democratising access to finance - risk reinforcing the centrality of platform monopolies that control data, algorithms, and transaction flows. These insights are particularly relevant for the analysis of central bank digital currencies (CBDCs), as they too operate through highly centralised technological infrastructures.

Financial inclusion initiatives may simultaneously generate new dependencies by exposing individuals and businesses to intensified forms of surveillance and algorithmic governance. This echo concerns that the pursuit of inclusivity could inadvertently legitimise a neo-feudal order in which central banks and Big Tech assume the role of digital overlords.

The emergence of CBDCs illustrates this dilemma: while designed to enhance inclusivity, they also embody an institutional centralisation that risks marginalising civic participation and reinforcing hierarchical relations (Adams & King, 2025; Fitz & Scheeg, 2025). This critique resonates with broader discussions on the “post-democratic” tendencies of digital governance (Crouch, 2022), where formal democratic mechanisms persist, but technocratic and corporate elites increasingly exercise real power.

At the same time, empirical studies underscore the ambivalent role of digital financial instruments (Xu et al., 2025). The IMF (2023), BIS (2023), Hemingway (2025), Gafsi (2025), Sayyid, Grosman and Klarin (2025), and Kumar (2025) highlight the potential of CBDCs to reduce transaction costs, increase financial transparency, and foster small business development.

McKinsey (2024), Forbes (2024), and Cumming et al. (2025) highlight the democratising promise of asset tokenisation, which lowers entry barriers for investment and increases liquidity. Yet other scholars warn of the paradoxical outcomes of these innovations. McCormack (2024) stresses that tokenised assets must comply with the principle of "singleness of money" to maintain trust. In contrast, Baltgailis Doronina & Mahmudova (2024) argue that CBDCs may transfer client bases from private banks to central banks, subjecting businesses and citizens to unprecedented forms of centralised control.

Critical sociology and political economy interpret these trends as signs of an emerging “digital aristocracy.” Scholars such as Stone and Kuttner (2020) and Structural Lens (2025) argue that control over digital

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infrastructures - communication platforms, payment systems, and artificial intelligence - replicates feudal-like hierarchies, where access and exclusion are determined by a small group of powerful actors (Pan et al., 2025). From this perspective, financial inclusion is not necessarily synonymous with democratisation. Still, it can be a vehicle for new inequalities, where dependence on state and corporate digital systems replaces traditional forms of economic exclusion.

Taken together, the literature demonstrates a profound ambivalence in the nexus between inclusive economies and digital transformation. While CBDCs, asset tokenisation, and digital platforms are promoted as vehicles for financial inclusion and social progress, critical scholarship suggests they may simultaneously consolidate state and corporate power, reproduce structural inequalities, and facilitate the emergence of digital neo-feudalism. This duality underscores the need for further research on institutional safeguards, democratic accountability, and ethical frameworks that can ensure the inclusivity agenda does not inadvertently foster new forms of economic and political dependence.

3. Theoretical basis and methodology of the research

A Central Bank Digital Currency (CBDC) represents a liability of the central bank and serves as a digital version of a nation's sovereign currency, issued by the central bank and supported by government credit. Although the introduction of CBDCs entails significant initial investments in the development of necessary technological infrastructure, it is expected to reduce long-term transaction costs and foster financial inclusion. One of the key aspects of CBDC implementation lies in the unprecedented level of oversight it provides over customer transactions. Since user accounts are directly linked to the central bank, authorities gain enhanced capabilities to monitor money flows and combat illicit activities such as money laundering. This, in turn, can improve tax collection efficiency, strengthen social protection mechanisms, and support the development of a more inclusive economy.

The essential distinction between a CBDC and the forms of "digital money" currently available to consumers—such as bank cards or mobile payment applications—lies in the fact that CBDCs are a direct obligation of the central bank rather than of commercial banks. CBDCs can take three main forms: wholesale (token-based) and two types of retail (token-based and account-based). The differences between them primarily concern the degree of accessibility and the technological foundation. Retail CBDCs are designed for everyday use in consumer transactions, providing a convenient and inclusive payment option. In contrast, wholesale CBDCs are limited to financial institutions and are primarily used to facilitate the settlement of large-scale interbank or financial market transactions in digital form.

There are three principal architectural models for retail CBDCs, all of which involve the central bank as the sole issuer and redeemer of the digital currency. In the indirect, or two-tier, model, the central bank distributes CBDCs to the public through intermediaries such as commercial banks, and the consumer's claim rests with the intermediary. In the direct CBDC model, the central bank itself manages all payment processing in real time and maintains the full record of retail account balances. The hybrid model incorporates elements of both systems: consumers hold claims directly against the central bank, while payment processing is handled by intermediaries operating in real time (Baltgailis, Doronina & Mahmudova, 2024).

The ongoing integration of both fiat and digital currencies into modern payment infrastructures has stimulated an active process of asset tokenization. One potential model of CBDC implementation envisions offering digital currency in the form of deposit accounts held directly with the central bank, available to households and businesses alike. While such an expansion is not conceptually innovative, it poses significant technological and operational challenges.

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2025 Volume 13 Number 2 (December)
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A deposit-based CBDC model appears to be the most straightforward approach and provides stronger safeguards against money laundering. This structure also ensures a high degree of security and control over the total volume of money in circulation, while maintaining its legal validity and compliance with established standards for payments and economic transactions. Under this model, each CBDC unit would be strictly personalized, granting the central bank the ability to monitor and oversee all customer transactions in real time.

The central bank could offer a digital token currency that would circulate in a decentralised way without a central ledger. This is often associated with anonymity, meaning that the central bank would not know who currently holds the issued tokens (as is the case with banknotes).

Based on mathematical modeling, the International Monetary Fund has estimated that the introduction of a CBDC leads to a 2.2% increase in total lending. This effect is primarily driven by a 17-percentage-point rise in the proportion of the population holding a bank account—from 75% to 92%. Such an expansion in financial inclusion compensates for the disintermediation effect typically associated with CBDC adoption, namely, the transfer of savings from traditional deposit accounts to CBDC wallets. It is projected that around 14% of bank account holders (equivalent to 13% of the total population) would prefer to store their savings in CBDC rather than in deposits. Consequently, the share of individuals saving through deposit accounts increases by 5 percentage points (from 75% to 80%) following CBDC issuance, thereby supporting credit expansion. Furthermore, 47% of the population is expected to use CBDC for payments. Overall, aggregate returns from investments in household production technologies grow by 5%, while total household welfare (utility) rises by 0.19% as a result of CBDC introduction (IMF, 2023).

The tokenization of money and assets presents significant transformative potential; however, existing initiatives have largely been developed in isolation, lacking integration with central bank money and the institutional trust it provides. Currently, efforts toward centralization are emerging, aiming to establish mechanisms that allow for coordinated oversight of operations across both public and private blockchain networks. A new form of financial market infrastructure - the unified ledger - has been proposed as a means to fully realize the advantages of tokenization. This system would integrate central bank money, tokenized deposits, and tokenized assets within a single programmable platform.

By consolidating all components into a unified environment, such a ledger enables the automatic execution of a wider range of contingent actions, thereby addressing traditional information asymmetries and incentive-related inefficiencies. Furthermore, the system should be designed for interoperability with external third-party technology platforms and applications that support essential financial operations, including securities settlement, exchange and clearing processes, and cross-border payments. In cases where these external systems employ distributed ledger technology, the deployment of smart contracts across platforms would enhance the programmability of both cash and payment mechanisms. Functionally, this approach allows participants to manage their entire liquidity and collateral portfolio virtually through a single, integrated “liquidity pool,” eliminating the need to maintain fragmented reserves across multiple correspondent accounts, nostro relationships, or domestic central securities depositories (BIS, 2023).

At the same time, many countries are establishing comprehensive frameworks for licensing, supervision, and auditing of issuers and participants in the cryptocurrency market. The Markets in Crypto-Assets Regulation (MiCA) represents the European Union’s legislative framework designed to regulate the cryptocurrency sector, particularly focusing on the issuance and listing of crypto-assets on trading platforms. MiCA also introduces mechanisms to prevent market abuse by defining rules on the disclosure of insider information, prohibiting insider trading, and restricting manipulative practices that may distort the value or trading of crypto-assets.

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2025 Volume 13 Number 2 (December)
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The ongoing competition between central bank digital currencies (CBDCs) and privately issued digital currencies constitutes a critical factor in shaping the future of the global monetary system. According to the Bank for International Settlements (BIS), one of the fundamental principles of financial stability is the "singleness of money," meaning that all forms of money - whether publicly issued (e.g., cash) or privately issued (e.g., bank deposits) - should trade at par and not be subject to exchange rate fluctuations among themselves. As McCormack (2024) notes, institutional investors are unlikely to place trust in a digital currency that fails to uphold this principle, as it undermines monetary coherence and reliability.

If private digital currencies, such as stablecoins, were to dominate client transactions by offering faster and cheaper payment alternatives outside of regulatory oversight, this could jeopardize the stability of CBDCs and weaken their ability to maintain a 1:1 exchange ratio with both fiat "electronic money" and physical cash. Such developments could, in turn, erode public confidence in central banks. This concern underlies the rationale behind the decisions of governments such as those of China and India to prohibit the circulation of private cryptocurrencies within their jurisdictions - measures explicitly aimed at preserving the stability and credibility of their national CBDCs (Baltgailis, Doronina & Mahmudova, 2024). Today, by banning private currencies, China has created an international system of stable settlements in its state cryptocurrency, which is already trusted by 16 countries and can potentially spread globally.

The People's Bank of China has announced a major development in international finance: the digital renminbi (RMB) cross-border settlement system has been fully integrated with the ten ASEAN member states and six countries in the Middle East. This expansion significantly broadens the reach of the digital yuan, establishing interoperability across nearly 38% of global trade and allowing participants to conduct transactions without using the SWIFT network, which has traditionally underpinned the dominance of the US dollar. A defining feature of this transformation is the digital RMB's ability to support international settlements independently of both SWIFT and the dollar. Historically, SWIFT has been the principal channel for interbank communication in cross-border transactions. However, the system's inherent dependence on the US dollar has been viewed by many nations as a strategic constraint on their economic autonomy. By introducing an independent digital payment infrastructure, China provides a viable alternative for countries seeking to minimize dollar reliance. The new digital currency bridge developed by China enables settlement within just seven seconds. In a pilot transaction between Hong Kong and Abu Dhabi, a payment from a Chinese enterprise to a Middle Eastern supplier was executed in real time, bypassing six intermediary banks and reducing transaction costs by 98% (Invest Offshore, 2025).

The consequences of this development go well beyond gains in speed and efficiency. The digital RMB's blockchain-based framework incorporates built-in regulatory and compliance mechanisms, including traceability and anti–money laundering safeguards, embedded in each transaction. Currently, more than 87% of countries worldwide are compatible with China's digital RMB infrastructure, with cumulative cross-border payments exceeding USD 1.2 trillion. While the United States continues to deliberate over the future role of the dollar in the era of digital finance, China has already established a blockchain-enabled global settlement network encompassing over 200 countries (Invest Offshore, 2025).

Payment and settlement operations, as well as non-cash circulation, are based on the interbank payment system. Digital currencies of central banks, as the name suggests, imply a monopoly on their issuance by central banks, making it unnecessary for commercial banks to expand the money supply. Thus, the central bank will be the creator, operator, and custodian of the digital currency pool - a digital Euro based on deposit accounts directly with the central bank.

The monopoly of the central bank, according to the developers, should create opportunities for the formation of an inclusive economy and enable the state, in cooperation with Digital platforms (Big Data), to take control of all business and human initiatives, which creates the basis for the emergence of neo-feudalism**.** In addition to the

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2025 Volume 13 Number 2 (December)
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development of a two-tier banking system, international developers admit and propose a single-tier banking system, in which there is an even greater concentration of power between the Central Bank and "big data", and there are no intermediaries in the form of commercial banks (Baltgailis, Simakhova & Buka, 2025).

This emerging aristocracy draws its authority not from the possession of land or subjugation of peasants, but from its control over the digital infrastructure that now structures nearly every aspect of human life. Social media networks, payment platforms, communication systems, and artificial intelligence technologies constitute the essential infrastructure of the contemporary world. Mastery over these systems endows their owners with a form of power strikingly reminiscent of that wielded by medieval lords—the power to allow or restrict, to amplify or silence, to grant participation or enforce exclusion (Structural Lenz, 2025).

In addition, the European Commission is pushing for countries to start storing data on citizens en masse, despite this being officially prohibited in Europe as a serious violation of fundamental human rights. According to the Commission's plan, service providers will be required to store large-scale information about individuals. In the Commission's interpretation, this includes information about the user, sender, and recipient of the message, the location of the device, date, time, duration, as well as any other data that does not contain the text or content of the message. Until now, the principle in the European Union has been that such data must be deleted immediately after it is no longer needed, as it concerns the private lives of citizens. Long-term storage of such data was considered a violation of the fundamental right to privacy.

Although constitutional safeguards protect citizens from unwarranted government surveillance, technology corporations often possess far more extensive information about individuals—frequently obtained with their nominal “consent.” The major technology companies have consistently resisted regulatory attempts to limit or oversee their collection and use of personal data (Patil et al., 2025).

Major technology corporations such as Google, Apple, and Amazon have effectively developed their own regulatory frameworks—often embedded within complex and opaque terms of service—that govern users’ consent regarding the commercial use of personal data (American Prospect, 2020).

Despite the rise of digital payment methods, cash continues to play a significant role as a medium of exchange worldwide, particularly in developing economies. Even in Europe, which is frequently considered a leader in payment innovation, cash accounted for 52% of transactions in 2024, according to the European Central Bank (Mastercard, 2025). Most central banks have affirmed their commitment to issuing and distributing physical currency as long as there is demand. However, just as payment cards, real-time transfers, and digital wallets have expanded the range of payment options and enhanced transactional security, central bank digital currencies (CBDCs) offer similar potential. Proponents of CBDCs argue that they can reduce the inefficiencies and costs associated with the production and distribution of physical money, which can amount to as much as 1.5% of a country’s GDP (Mastercard, 2025). Furthermore, as internet connectivity and smartphone adoption continue to increase, CBDCs may serve as a mechanism to bring financially excluded populations into the digital economy. From a critical perspective, the decline of cash can be interpreted as a facet of neo-feudalism, increasing individual dependence on state-controlled and corporate-managed digital infrastructures. In response to such concerns, six countries—Austria, the Netherlands, India, Mexico, Hungary, and Slovakia—have constitutionally protected the right of citizens to use cash (Bautista-González, 2022), and a similar legislative initiative was proposed in Latvia.

The monetization of assets is particularly evident in the context of asset tokenization. Essentially, existing fiat and digital financial instruments, along with tangible goods and services, can be transformed into monetary assets, acquiring a new digital form that allows them to be actively traded on blockchain-based platforms without intermediaries, with Big Data playing a central role in value extraction and management. Tokenization of Real-

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2025 Volume 13 Number 2 (December)
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World Assets (RWA) entails converting ownership rights over a broad spectrum of assets - including bonds, equities, real estate, and cultural properties - into blockchain-based digital tokens (Figure 1). This technological innovation has the potential to improve liquidity, increase transparency, and enhance accessibility, thereby democratizing asset ownership and creating new opportunities for market participation.

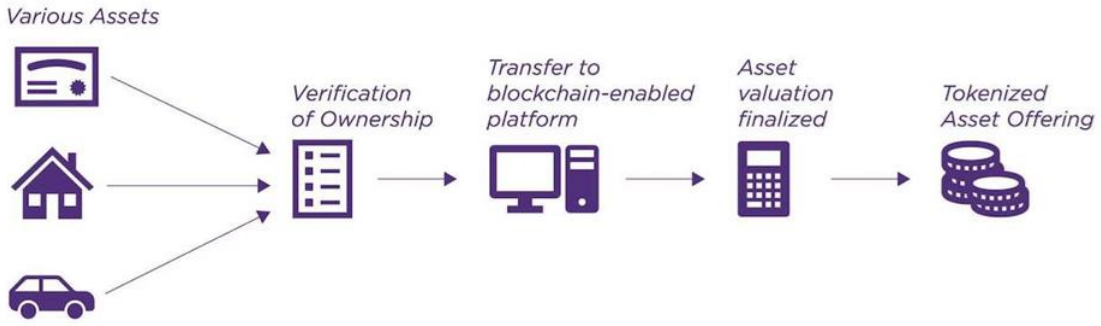


Figure 1. The process of asset tokenisation.
Source: elaborated by the authors

Blockchain technology is central to these digital transformations, functioning as a secure and immutable ledger that ensures data is recorded and maintained without the possibility of unauthorized alteration, duplication, or deletion. Serving as a digital "book of trust," blockchain bridges the physical and digital realms. Through distributed ledger technologies (DLT), the concepts of trust and transparency are redefined, enabling physical objects or rights to be digitally represented via unique identifiers. Tokenization further enhances these assets by granting them new attributes that can be leveraged in economic and financial activities.

In a digital economy where trust is critical, several dimensions are essential for establishing confidence: trust in content, identity, ownership, authenticity, and accuracy. Tokens play a foundational role in this context, representing physical assets digitally while simultaneously extending their functional capabilities. They encapsulate both identity and value within a digital protocol, providing a reliable mechanism for participation in digital markets.

The primary objective of asset tokenization is to create a more accessible and liquid means of investment. By dividing assets into smaller shares represented by digital tokens, investors can acquire portions of high-value assets at a lower cost. Tokenized assets facilitate easier trading and ownership transfer, as these digital tokens can be efficiently exchanged on online platforms. This process exemplifies the monetization of assets: existing fiat and digital financial instruments, along with real-world services and tangible production, are transformed into monetary assets. In this transformation, the intrinsic nature of these assets is converted into a new digital monetary form, enabling active trading on decentralized platforms without intermediaries, with Big Data playing a central role in extracting value and driving efficiency (Figure 2).

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2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/s4626758963

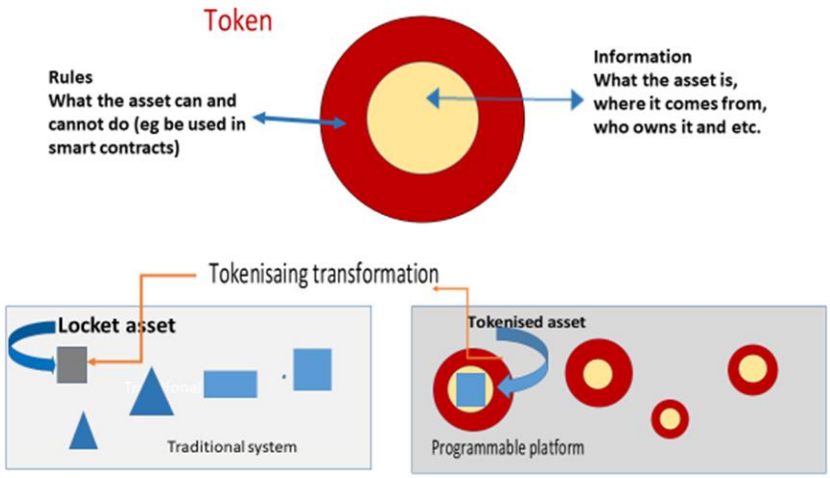


Figure 2. Asset tokenisation
Source: BIS, 2023

Entrepreneurs should now consider engaging simultaneously in both centralized (CeFi) and decentralized (DeFi) financial markets. The emergence of state-issued digital currencies, or CBDCs, changes the landscape significantly, as these currencies are issued exclusively by central banks and require accounts directly with the central bank for their use.

For businesses, critical factors include low transaction costs, rapid currency exchange, and fast payment settlement. These advantages reduce operational expenses, enhance partner confidence, and strengthen overall business stability. Such benefits are particularly vital in countries with politically or economically unstable environments and volatile local currencies. A survey of 2,541 adults across Brazil, India, Indonesia, Nigeria, and Turkey found that 47% use stablecoins to achieve higher savings rates, 43% for more efficient currency conversion, and 37% to access US dollars. Although the sample is limited, these results indicate that stablecoins are evolving into versatile financial instruments in emerging markets, addressing economic needs beyond conventional cryptocurrency uses (Crypto Valley Journal, 2024).

According to McKinsey, the tokenized market capitalization across asset classes could reach approximately USD 2 trillion by 2030, excluding cryptocurrencies and stablecoins, with pessimistic and optimistic estimates ranging from USD 1 trillion to USD 4 trillion, respectively. These figures deliberately omit stablecoins - including tokenized deposits, wholesale stablecoins, and CBDCs - to prevent double-counting (McKinsey & Company, 2024). Tokenization remains a strategic priority for BlackRock, which aims to tokenize USD 10 trillion in assets through partnerships (Forbes, 2024). In this context, tokenized assets on trading platforms not only facilitate broader market participation but also provide digital giants with opportunities to amplify cash flows. This, in turn, allows these entities to direct the redistribution of resources according to their own interests rather than public priorities, highlighting the central role of tokenization in shaping the emerging inclusive digital economy.

This entire tokenisation process is taking place against the backdrop of the new US administration's attempts to strengthen the dollar's global position and make the digital dollar the world's leading currency. US presidential adviser Stephen Miran argues that the US dollar has been continually overvalued due to its status as a reserve currency. This has benefited financially driven sectors of the economy and wealthy Americans, but has placed a burden on American manufacturing by making it cheaper to import from abroad. In his view, these tensions will

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2025 Volume 13 Number 2 (December)
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be resolved by policies that preserve the dollar's status but improve burden sharing with trading partners. International trade policy will attempt to recapture some of the benefits that the dollar's reserve status transfers to trading partners and link that economic burden sharing to defence burden sharing (Financial Post, 2025).

4. Research results and discussion

While our citizens are constitutionally protected from unreasonable searches and seizures, the tech giants know far more about us, often with our "consent," than the government does. The giant tech industry quietly pays fines for trying to force the government to regulate its use of personal data. We have already said that there are companies that invent their own rules and laws to regulate consumer consent for the commercial use of personal data. There is an active battle for the personal data of the population, with massive customer databases being stolen and resold worldwide, enabling digital giants to influence the politics and economy of countries directly. Refer to Figures 3 and 4 to see how the mounting fines are affecting corporations that use personal data illegally in their business operations. In the absence of compensating government regulation, the digital industry will create its own private law, using its market power to increase profits and protect itself from competition or government oversight. In any case, the development of an inclusive economy to a certain extent ensures greater employment, improved social well-being among the population, without revolutionary upheavals and other shocks, and supports economic stability. For the state and corporations, economic stability is the primary reason for supporting inclusiveness.

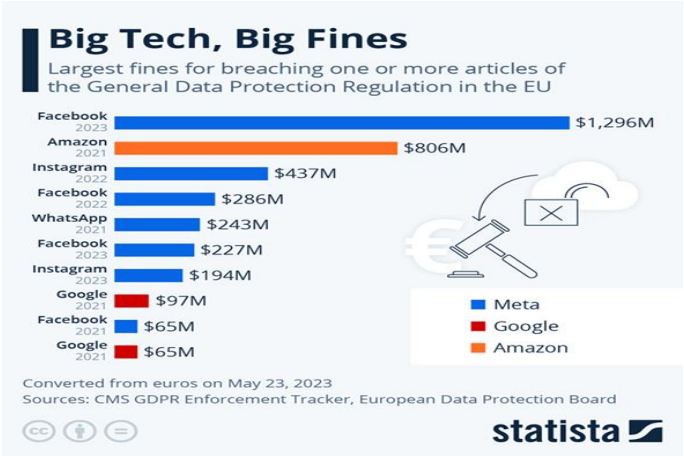


Figure 3. Big Tech, Big Fines
Source: Statista, 2023

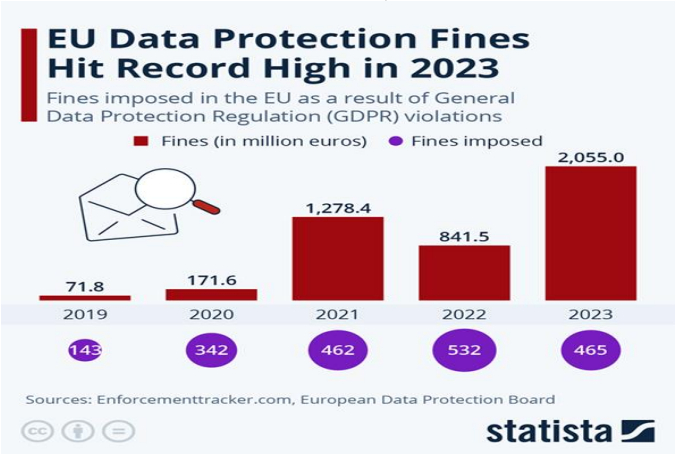


Figure 4. EU Data Protection Fines Hit Record High in 2023
Source: Statista, 2023

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The current situation is particularly alarming due to the convergence of three historical trends that have previously manifested independently: the transnational influence of capital, reminiscent of the late 19th century; the close alignment of wealth with authoritarian political power, echoing patterns from the 1930s; and the emergence of unprecedented technological capabilities for social surveillance and control. Together, these factors create opportunities for authoritarian oversight and influence on a scale that would have been unimaginable to earlier generations (Structural Lens, 2025).

As we have already noted, the new aristocracy derives its power from the possession of digital infrastructure, which is increasingly becoming a mediator of human existence, and control over it is becoming key in the system of struggle for influence in the global economy. The growing possibility of neo-feudalism formation will be supported by the global economy, where the most powerful and technologically advanced players are attempting to determine the rules of the game. In the context of growing competition in the global economy between the state and Big Tech for power and client assets, neo-feudal forms of organising public life may become a clear result of competitive struggle.

The development of an inclusive economy may lead to a similar process of enclosing sheep pastures, which reached its largest scale in Britain between the 15th and 19th centuries, creating conditions for the release of labour in agriculture and its redirection to cities for the development of the textile industry. In the emerging digital environment, an inclusive economy, first of all, creates opportunities for small and medium-sized businesses to open accounts in the Central Bank, which issues state digital money, facilitates the conditions for obtaining loans, ensures a reduction in payment fees and creates stable and safe working conditions, eliminating the risk of bankruptcy of intermediaries in the form of commercial banks. Thanks to this, small and medium-sized businesses will shift from private banks to the Central Bank, where they will come under the close supervision and control of state structures. In this case, artificial intelligence can be used to track clients' credit histories directly at the Central Bank, prevent money laundering attempts, and strictly enforce tax policy. If clients start working through private digital platforms, then, thanks to new legislation, the latter will be obliged to save all information about client transactions, which can be obtained upon request by almost any government agency. It is worth noting that even in blockchain systems, issues with data availability persist. Decentralisation, the fundamental principle of blockchains, depends on the availability of data. This allows all participants to verify transactions and blocks without relying on a central authority. This increases the stability of the network.

On the other hand, the disadvantage is the complexity of integrating blockchain into traditional systems. Many organisations face challenges when attempting to integrate decentralised technologies into their established infrastructure. The need to restructure business processes can become a serious obstacle to large-scale applications. In addition, legal uncertainty and the lack of uniform standards also affect the speed of technology dissemination, requiring regulators to develop new approaches to regulating digital assets. In the blockchain system, all information about participants is stored almost indefinitely, and if the state wants to obtain this information, it can do so in principle. Many countries have developed regulations for cryptocurrencies, and yet no country has fully determined how to implement the regulations. A significant part of the challenge lies in classifying cryptocurrencies within existing financial frameworks. Taxing or regulating a cryptocurrency as a currency, a security, or an asset is challenging, as a cryptocurrency can be classified as any one, two, or all three. As a result, an inclusive economy can create the opposite effect, where all economic activity, rather than a democratic process of increasing efficiency, falls under the monopoly control of the state, especially if it is a totalitarian state.

The monopoly of the central bank, according to the developers, should create opportunities for the formation of an inclusive economy and enable the state, in cooperation with Digital platforms (Big Data), to take control of all business and human initiatives, which creates the basis for the emergence of neo-feudalism. In addition to the development of a two-tier banking system, a one-tier banking system is also proposed, where there is an even

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2025 Volume 13 Number 2 (December)
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greater concentration of power between the Central Bank and Big Data, and where there are no intermediaries in the form of commercial banks.

Increasingly, proposals are being made to develop new democratic financing mechanisms that are independent of traditional financial systems, which are becoming increasingly subject to oligarchic control. It is proposed to establish an international system to prevent the algorithmic manipulation of public discourse, to develop new antitrust mechanisms that address the issue of data monopolies, and to create state alternatives to private digital platforms. However, it is essential to understand the sources of investment for these developments clearly. If the state is closely connected with digital giants, which often have resources more global than the state itself and operate worldwide, then such a state will not support these efforts or may even slow them down. In addition, legal uncertainty and the lack of uniform standards also affect the speed of technology dissemination, requiring regulators to develop new approaches to regulating digital assets. In the blockchain system, all information about participants is stored almost indefinitely, and if the state wants to obtain this information, it can do so in principle. Many countries have developed regulations for cryptocurrencies, and yet no country has fully determined how to implement the rules. A significant part of the challenge lies in classifying cryptocurrencies within existing financial frameworks. Taxing or regulating a cryptocurrency as a currency, a security, or an asset is challenging, as a cryptocurrency can be classified as any one, two, or all three. Such unsettled legislation hinders the development of international audit standards in the field of digital money, a system of licensing market participants and, first of all, the Decentralised Market of Financial Assets (DeFi), creates advantages for private digital giants in the field of settlements and taxation, and does not protect the population from financial feudal lords.

Conclusions

The development of an inclusive economy, while offering opportunities to enhance financial access and social stability, simultaneously raises significant concerns regarding the concentration of power in the hands of digital platforms and central banks. Central bank digital currencies (CBDCs) and the tokenisation of assets represent significant technological advancements that promise to reduce transaction costs, enhance financial transparency, and support the development of small and medium-sized businesses. However, these innovations are not without risks. The centralisation of financial systems under CBDCs and the widespread adoption of digital platforms can lead to the creation of new forms of economic and political dependence. In many ways, this convergence of state power and corporate dominance over digital infrastructures mirrors historical feudal structures, where a small elite determined access and exclusion. The literature reviewed highlights the ambivalence of these developments, suggesting that while they hold the potential to democratise finance, they may simultaneously reinforce digital monopolies and state control. Moreover, the emergence of a "digital aristocracy," as described by critical scholars, raises pressing questions about the balance between financial inclusion and the risk of exacerbating inequalities within the digital economy. The concentration of wealth and power within the hands of a few tech giants and state-controlled financial systems may undermine the very principles of inclusivity it seeks to promote.

Ultimately, while the inclusive economy framework offers valuable avenues for reducing inequality and promoting economic participation, it also necessitates careful consideration of ethical, institutional, and regulatory safeguards. Without such measures, the push for financial inclusion may pave the way for a new digital form of neo-feudalism. Policymakers, regulators, and academics must engage in a nuanced discussion to ensure that the promises of digital financial technologies are realised without undermining democracy, privacy, and social justice. As the global economy becomes increasingly intertwined with digital platforms and state digital currencies, the challenge will be to harness these technologies for the common good while preventing the monopolisation of power by a select few.

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SUSTAINABILITY AND GREEN MANAGEMENT IN HOSPITALS*

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Abstract. Public sector organizations are also increasingly focusing on assessing the environmental impact of their activities. Sustainable principles in hospitals mean ensuring high-quality, safe, cost-effective care that minimizes negative impacts on society and the environment. Efficiency and rationalization of production resources are essential conditions for sustainable healthcare. The approach of hospitals to sustainability is thus changing. Hospital management is adopting management and strategy development approaches that integrate elements of green management. Despite the growing importance of environmental management in hospitals, this area remains insufficiently researched in the Czech Republic, representing a significant research gap. The article, therefore, aims to map and assess the extent to which elements of green management are used in hospitals in the Czech Republic, focusing on environmental strategy, energy management, and employee training in sustainability issues. The research was nationwide in scope and covered all hospitals in the Czech Republic. Fisher's exact test was used for statistical verification of the proposed hypotheses. The results showed no statistically significant correlation between hospital size and the presence of an environmental policy or strategy. Although hospitals with a defined environmental strategy are more likely to address energy savings, the difference between the groups was not statistically significant. On the contrary, it was confirmed that hospitals with an environmental policy significantly more often and more systematically implement training or education of employees in the area of sustainability.

Keywords: energy; environmental strategy; green management; healthcare organizations; sustainability

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1. Introduction

In recent decades, global environmental issues have reached alarming levels, posing significant threats to ecosystems, human health, and economic stability (Tanveer et al., 2025). Hospitals are one of the most important elements of the public sector and play a crucial role in every country's healthcare system. Healthcare facilities are pivotal in ensuring continuous access to services, particularly for individuals with complex health conditions (Tjebane & Musonda, 2025). On the other hand, hospitals play a key role in contributing to environmental degradation, as they produce biological, pharmaceutical, chemical, and radioactive waste that poses significant health risks (Zikhathile et al., 2022). Waste disposal poses a potential risk to the environment, which is why waste collection from healthcare facilities is a key environmental issue (Lattanzio et al., 2022). In the Czech Republic, hospitals are classified according to size as large (500 or more beds), medium (101-499 beds), and small (fewer than 100 beds). This classification was also the categorization criterion for nationwide research.

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The importance of these entities can also be assessed from a microeconomic perspective, where adequate healthcare increases the population's productivity and reduces losses to businesses caused by long-term sick leave. The macroeconomic significance is also key, as the healthcare sector is one of the largest employers and expenditure is a significant item in public budgets.

From this perspective, the healthcare sector is considered very complex due to the interdependencies between its various entities that provide care to patients and the population (Larsen et al., 2021). The rapid increase in healthcare costs has drawn the attention of managers and policymakers towards regulating health expenditures: many countries have implemented deep reforms to improve efficiency and productivity in the provision of health services (Fulgenzi & Gitto, 2024). The main objective of these entities is to provide high-quality care to patients while rationalizing resources, not only financial ones.

The management of healthcare facilities has its own specific characteristics, as in addition to the main goal of providing high-quality medical and nursing services, there is also a financial and economic goal. The management of healthcare facilities and a properly set strategy are essential for the effective provision of healthcare. Healthcare in the Czech Republic is one of the areas where insufficient attention has been paid to the environmental impact of the organization's operations. In recent years, there has been growing pressure to improve all processes, increase the quality of healthcare, and implement sustainability principles in the hospital sector (Ahlstrom et al., 2025; Zeferino et al., 2025). Good management practice has long been seen as critical to improving the performance, quality, and efficiency of healthcare systems (Ban et al., 2024). Better hospital management practice has been shown to correlate with improved clinical quality and performance (Dorgan et al., 2025). Hospital management practices are of fundamental importance in reducing costs, improving the quality of healthcare, and thus increasing customer satisfaction among the population. Hospital management is quite complex due to constant challenges involving clinical, economic, managerial, and humanitarian aspects (de Oliveira, 2024).

The reason why it is important to address sustainability issues in hospitals is simple. Hospitals operate continuously, 24/7, and use energy-intensive technologies (diagnostic equipment, sterilization, cooling, heating, ventilation) (Lattanzio et al., 2022). Green management is therefore particularly important in hospitals, as their operations and medical technologies make them among the most energy-intensive public facilities. The introduction of sustainable and environmentally friendly energy-saving measures can significantly reduce operating costs, lower the carbon footprint, and contribute to national and EU climate goals. At the same time, efficient energy management supports the sustainable development of healthcare services by freeing up resources that can be redirected to patient care and technological improvements.

2. Literature review

Environmental aspects of sustainable healthcare

At a time when environmental issues are more pressing than ever, organizations are increasingly recognizing the importance of integrating sustainability into their core practices (Tanveer et al., 2025). Sustainability refers to development that meets current needs without compromising the needs of future generations (Malik et al., 2021). Sustainability issues are crucial in today's competitive environment (Riaz et al., 2025). In response to these current environmental and resource economy challenges, sustainability is becoming a strategic goal for hospitals. Sustainability represents a balance between production and consumption with regard to the rationalization and economy of input resources. According to Olawumi and Chan (2018), environmental sustainability is the practice of preserving ecosystems through responsible consumption and replenishment of the natural resources that support life on the planet. Sustainable healthcare means providing affordable, quality medical care without causing undue environmental damage (Rahat et al., 2024). Environmental strategy can be defined as a series of initiatives that aim to reduce the operational impacts on the environment through the company's products, processes, and policies using sustainable resources and environmental management systems (Leyva & Parra, 2021). The integration of green and sustainable principles into an organization's strategy undoubtedly has an impact on competitiveness and economic growth in the long term (Bashar et al., 2025; Jianbing et al., 2025; Zhang & Zhu, 2025). Accordingly, incorporating environmental sustainability into

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2025 Volume 13 Number 2 (December)
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healthcare services poses a unique challenge since hospitals must strike a balance among service quality (i.e., clinical quality and patient experience), cost efficiency, and environmental footprints (Han et al., 2024).

From a sustainability perspective, hospitals contribute to all three pillars. Healthcare facilities have an impact not only on the health and productivity of the population, but also on the economy, the environment, and social stability. The three dimensions of sustainability (economic, environmental, and social) influence how people perceive and strive for sustainability in their environment (Alsawaf & Albadry, 2022). In terms of material and energy consumption, hospitals are among the most demanding public institutions. They produce large amounts of waste and consume significant amounts of water and electricity. The healthcare sector is responsible for 5% of the carbon footprint in the member countries of the Organization for Economic Cooperation and Development (Pichler et al., 2019). The integration of sustainable practices into hospital management, including energy-saving and environmental initiatives, improves the overall sustainability of hospitals (Dion & Evans, 2024).

Green management practices are essential for organizational sustainability, and their adoption in hospitals can help reduce environmental impact (Yassin et al., 2025). Green management refers to a philosophy, technology and methodology of organization management aimed at optimizing the effect of its operation on the environment. Its principal goals are economical use of materials, energy and other resources, economical processes and the reduction of factors posing a burden for the environment (Scholz et al., 2022). Green management in hospitals involves a combination of sustainable and environmentally friendly practices aimed at reducing the environmental impact of these organizations. Studies (Alhemimah et al., 2025; Saipidinov et al., 2025) examine the complex impacts of green management as an essential element of business for all types of organizations and its influence on environmental, economic, and social performance. Environmental sustainability (ES) is increasingly important in healthcare because it promotes more efficient operations and cost savings. A study (Vaishnavi & Suresh, 2023) examines the factors that improve ES performance in hospitals and offers insights for professionals on how to implement effective environmental practices.

Energy saving strategies and environmental impacts of hospitals

Healthcare facilities, which are crucial to society, pose particular challenges in terms of energy sustainability due to their continuous operation and strict hygiene standards (Silva et al., 2024). Among the environmental issues to be addressed are the high levels of energy consumption and waste production, as well as the inefficient use of resources encountered by traditional healthcare systems.

Hospitals are among the most energy-intensive buildings, operating non-stop throughout the year. This requires a stable supply of electricity, heat, and water, which leads to increased energy consumption. The healthcare sector contributes significantly to the increase in greenhouse gases, so it is essential that hospital facilities increase their energy efficiency and introduce renewable energy sources (Schwab et al., 2025). This claim is supported by a study by Darko et al. (2017), which adds that hospitals are the second largest consumers of energy after offices and a significant contributor to emissions from the incineration of medical waste. Therefore, special attention must be paid to the design and construction of hospital buildings (Aini et al., 2023). The implementation of energy-saving measures, such as green energy and consumption optimization, is key to reducing the carbon footprint of hospitals. Hospital buildings have special significance in every society because the way this type of building is designed, constructed, and operated has a profound impact on human health and the environment. There is growing interest in this sector, which deals with health aspects and sustainable construction to ensure compatibility with human health and surrounding natural environmental systems (Alsawaf & Albadry, 2022). Green innovations are a mechanism that can mitigate industrial pollution and minimize environmental impacts that are harmful to various industries, including hospitals (Takalo & Tooranloo, 2021).

Energy savings can help hospitals strengthen their resilience both economically (energy is a significant item of operating costs) and in terms of safety (savings help ensure operations in crisis situations). The main elements of these measures often include building insulation, energy-efficient lighting, smart consumption management, photovoltaics, etc. A significant innovation in building energy savings is the integration of artificial intelligence into energy management. In Europe, AI is transforming healthcare and energy management across the European

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Union's 27 member states (Pariso et al., 2025). As demonstrated by the study by Secinaro et al. (2021), the synergy between AI, hospital facilities, and energy management is paving the way for smarter, greener, and more efficient healthcare systems worldwide, contributing significantly to global sustainability goals and improved patient outcomes.

Green HRM strategy and employee training

Human resource management plays an important role in promoting sustainability; organizations are therefore increasingly focusing on individuals who are interested in green practices through the adoption of green human resource management and the potential it offers for achieving sustainability and building competitiveness (Allam & Mansour, 2024; Laužikas et al., 2025). The human resources department is one of the strategic resources within an organization (Atmoko et al., 2024). In the field of human resource management, green management is one way to set up systems to ensure environmental protection. Green management in human resource management integrates environmental goals into HR processes, which includes recruitment, training, compensation, and overall employee management. Green human resource management (GHRM) embodies a strategic fusion that not only advocates for environmental conservation but also aligns with the overarching goals of organizational performance. It is a discipline that requires the development of strategic policies and the execution of plans that are inherently eco-centric, fostering a workforce that is both environmentally conscious and operationally competent (Uslu et al., 2023; Chilunjika, & Uwizeyimana, 2024).

Green human resource management practices promote environmentally friendly behavior among employees and improve the overall sustainability of hospitals (Tassema et al., 2025). Training employees in sustainability and rational use of inputs is one of the key tools for maintaining environmental measures. Training helps change employee habits and behavior and increases motivation and responsibility. Roscoe et al. (2019) report that the implementation of green management in human resource management improves the long-term viability of an organization and its impact on the environment. Other studies that examine the impact of green management on green behavior among employees include Yadate (2025) and Priyashantha & Priyangaa (2022).

In this study, the authors focused on the link between formal policy required in organizations, practical environmental management, and people involvement. Although existing studies emphasize the importance of environmental management in the public sector, there is a lack of empirical evidence on how the implementation of environmental policies or strategies in hospitals translates into concrete measures, such as energy-saving measures and employee training in sustainability. Furthermore, most research focuses on the industrial context and business practices, while hospitals remain under-researched despite their high energy consumption and social role. This study aims to fill this gap by analyzing whether medium-sized and large hospitals with environmental policies are more likely to actively implement energy-saving measures and sustainability training.

3. Methodology

The aim of this article is to map the approaches and elements of Green Management in hospitals in the Czech Republic. In order to establish the theoretical basis for the research part, it was necessary to conduct a thorough analysis and synthesis of available literature sources and foreign studies. Contact details for hospital facilities were taken from the database of the Czech Ministry of Health. The basic categorization criterion was the size of the hospital according to the number of beds. First, the author team was interested in whether the hospital had an environmental policy or strategy in place. The author team's assumption was that large and medium-sized hospitals would meet this criterion. Based on an analysis of professional literature studies, it was proven that hospitals are very energy-intensive. The second research question was therefore to verify whether hospitals are actively seeking ways to save energy. People are a key element in the process of health and nursing care, so the last research question focused on the training of medical staff. Based on these hypotheses, a questionnaire with closed questions was compiled and sent to hospitals via the online tool Survio. The research sample consisted of 160 hospitals, with 31 correctly completed questionnaires returned, representing a response rate of 19%. The data was processed using general descriptive statistics, and Fisher's exact test was used to verify the hypotheses.

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2025 Volume 13 Number 2 (December)
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Based on the set objective, the team of authors was interested in whether the hospital sector has defined formal tools, policies, or strategies; how these strategies relate to practical measures (energy savings); and how these strategies affect the human factor. Three research questions were therefore formulated. These were subsequently verified by a quantitative questionnaire survey.

RQ1: Medium-sized and large hospitals have an environmental policy or strategy in place.
RQ2: Hospitals that have a defined environmental policy or strategy actively address energy savings.
RQ3: Hospitals that have a defined environmental policy or strategy actively train their employees in sustainability.

4. Results and discussion

Based on research questions formulated by the team of authors, two hypotheses were developed for each case. The first hypothesis is the null hypothesis and the second is the alternative hypothesis.

The hypotheses were formulated as follows:

RQ1: Medium-sized and large hospitals have an environmental policy or strategy in place.
H0: There is no statistically significant relationship between the size of the hospital and the existence of an environmental policy or strategy.
HA: There is a statistically significant relationship between the size of the hospital and the existence of an environmental policy or strategy.

The correlation between hospital size (based on the number of beds) and whether the hospital has an officially defined environmental policy or strategy was investigated. The results show that among small hospitals (fewer than 100 beds), only 33.3% (1 in 3) had a clearly defined environmental policy, 66.7% had a partially defined policy, and no hospital reported lacking such a policy. Among medium-sized hospitals (101–499 beds), 38.9% (7 out of 18) had an officially established environmental policy, 55.6% (10 out of 18) had a partially defined policy, and 5.6% (1 out of 18) stated that they did not have an environmental strategy. Among large hospitals (500 or more beds), an official environmental policy was present in 60% of cases (6 out of 10), 40% (4 out of 10) stated that they had a partially defined policy, and no hospital stated that it had no environmental policy at all.

When comparing responses by hospital size, an analysis was performed using Fisher's exact test (due to failure to meet the assumptions for using the chi-square test, as more than 20% of cells had expected frequencies less than 5). The results of Fisher's test did not show a statistically significant relationship between hospital size and the presence of an environmental policy or strategy ($p = 0.746$). **H0 was confirmed.**

Table 1. Association Between Hospital Size and Existence of an Environmental Policy or Strategy

		Does my hospital have a defined environmental policy or strategy?			
		Yes	Yes, partly	No	Total
Hospital size by number of beds	Small	1	2	0	3
	Medium	7	10	1	17
	Large	6	4	0	10
	Total	14	16	1	31

Source: Author's own research

Table 1 provides an overview of the association between hospital size and the existence of an environmental policy or strategy. The contingency table verifies relationship between these variables (Fisher's Exact Test, $p = 0.746$).

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2025 Volume 13 Number 2 (December)
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Table 2. The contingency table

Chi-Square Tests				
	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)
Pearson Chi-Square	1,907[a]	4	,753	,746
Likelihood Ratio	2,253	4	,689	,746
Fisher's Exact Test	2,749			,746
N of Valid Cases	31			

[a] 6 cells (66,7%) have expected count less than 5. The minimum expected count is ,10.

Source: Author's own research, 2025

One possible explanation for the insignificant relationship is that smaller hospitals may informally implement sustainability practices without formally documenting them in a written policy or strategy. This suggests that the existence of an environmental policy does not necessarily encompass the full range of green practices in healthcare facilities.

Nevertheless, a number of studies report a positive impact on performance improvement and cost reduction when integrating sustainability into strategies, such as Seifert and Guenther (2019); Seifert et al., (2020); Afsar et al., (2023). The role of hospital facilities in the development and implementation of sustainability strategies related to the provision of healthcare services was then examined in a study by Badanta et al., 2025. We must not forget the recent COVID-19 pandemic, which may have diverted management attention and resources away from sustainability initiatives (Lattanzio et al., 2022), highlighting the need for renewed support and strategic focus in this area.

Determining whether medium-sized and large hospitals have an environmental policy or strategy (RQ1) is a key starting point for assessing whether and how these formally defined documents influence practical sustainability measures. This question is followed by RQ2, which examines whether hospitals with an explicitly defined environmental policy or strategy actively implement measures leading to energy savings, thereby contributing to more efficient and environmentally friendly operations.

RQ2: Hospitals that have a defined environmental policy or strategy actively address energy savings.
H0: There is no statistically significant correlation between the existence of an environmental policy or strategy and the implementation of energy-saving measures.
HA: There is a statistically significant correlation between the existence of an environmental policy or strategy and the implementation of energy-saving measures.

Another research objective was to determine whether hospitals, as the most energy-intensive institutions, are actively addressing energy savings. The aim of this analysis was to verify whether hospitals that have an officially defined environmental policy or strategy (including partially defined ones) are also actively addressing energy savings. The results show that all hospitals that reported having an officially defined environmental policy (100%, 14 out of 14) also reported that they actively address energy savings. Among hospitals that have a partially defined environmental policy, 87.5% (14 out of 16) stated that they are addressing energy savings, while 12.5% (2 out of 16) stated that they are not actively addressing this area. Hospitals that do not have an environmental strategy at all are addressing energy savings in one case (100%, 1 out of 1). In terms of absolute frequencies, hospitals that address energy savings regardless of the degree of formalization of their environmental policy predominate.

Fisher's exact test was again chosen for statistical evaluation, as more than 20% of the cells in the contingency table had expected frequencies of less than 5. The results of Fisher's test did not reveal a statistically significant relationship between the existence of an environmental policy (including its level of definition) and active energy saving measures ($p = 0.518$). H0 was confirmed. Although it appears that hospitals with a defined environmental strategy are more likely to address energy savings, the differences between the groups are not

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statistically significant. The arguments for these results may be similar to those for RQ1. Hospitals can take a responsible approach to energy savings even if they do not have a sustainability strategy in place.

Hospitals and healthcare facilities require a range of engineering services, including heating, ventilation, and air conditioning systems, hot and cold water supply systems, and backup power systems (Al-Rawi et al., 2023). From this perspective, sustainable solutions are essential for hospitals in terms of energy resources. Dion et al. (2023) present options and plans for energy efficiency management in hospitals and healthcare facilities in their study. Vaishnavi & Suresh (2023) focused on resource conservation, namely reducing water consumption and using renewable energy sources. There are an increasing number of concepts for constructing green buildings that meet environmental goals (Aini et al., 2023). Alsawaf & Albadry (2022) published that hospital buildings must become sustainable, healthy, and technologically conscious, meet the needs of their occupants, and must be flexible and adaptable to deal with change.

Table 3. Association Between Environmental Policy and Energy Savings in Hospitals

		Does your hospital have an officially defined environmental policy or strategy?			
		Yes	Yes, partly	No	Total
We are actively involved in energy saving	Yes	14	14	1	29
	No	0	2	0	2
Total		14	16	1	31

Source: Author's own research, 2025

Table 3 provides an association between environmental policy and energy savings in hospitals. The contingency table 4 verifies relationship between variables.

Table 4. The contingency table

Chi-Square Tests				
	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)
Pearson Chi-Square	2,004[a]	2	,367	,518
Likelihood Ratio	2,775	2	,250	,518
Fisher's Exact Test	2,671			,518
N of Valid Cases	31			

[a] 4 cells (66,7%) have expected count less than 5. The minimum expected count is ,06.
Source: Author's own research, 2025

While the focus on active energy saving management represents the technical and operational aspect of hospitals' environmental strategy, the focus on the human factor is no less important. People and employees are also valuable resources that need to be invested in. Effective implementation of measures to promote sustainability requires not only technological solutions, but also a change in the attitudes and behavior of employees. Therefore, another research question focused on determining whether hospitals with a defined environmental policy or strategy actively implement employee training in the area of sustainability.

RQ3: Hospitals that have a defined environmental policy or strategy actively train their employees in sustainability.
H0: There is no statistically significant correlation between a defined environmental policy and an active approach to employee training in sustainability.
HA: There is a statistically significant correlation between a defined environmental policy and an active approach to employee training in sustainability.

The last part of the research examined the relationship between the existence of an environmental policy (or a partial form thereof) and the implementation of employee training or education in environmental sustainability. Of the hospitals that have an officially defined environmental policy, 64.3% (9 out of 14) stated that they conduct training regularly, 28.6% (4 out of 14) occasionally, and 7.1% (1 out of 14) stated that they do not yet

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conduct training but are planning to do so. No hospital in this group responded that it does not conduct training at all. Among hospitals with a partially defined environmental strategy, 43.8% (7 out of 16) stated that they conduct training occasionally, 18.8% (3 out of 16) regularly, 31.3% (5 out of 16) do not yet provide training but plan to do so, and 6.3% (1 out of 16) do not provide training at all. The hospital without an environmental policy (1 out of 31) stated that it does not provide training.

Table 5. Association Between Environmental Policy and Active Employee Training in Sustainability

		Does your hospital have an officially defined environmental policy or strategy?			
		Yes	Yes, partly	No	Total
Do you provide training or education for employees about environmental sustainability?	Yes	4	7	0	11
	Yes, regularly	9	3	0	12
	No	0	1	1	2
	No, but we are planning to	1	5	0	6
Total		14	16	1	31

Source: Author's own research, 2025

Fisher's exact test was again used to compare these groups. The test results showed a statistically significant association between the existence of an environmental policy and the implementation of employee training ($p = 0.014$). HA was confirmed.

Table 6. The contingency table

Chi-Square Tests				
	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)
Pearson Chi-Square	22,162[a]	6	,001	,003
Likelihood Ratio	14,195	6	,028	,016
Fisher's Exact Test	12,879			,014
N of Valid Cases	31			

[a] 9 cells (75,0%) have expected count less than 5. The minimum expected count is ,06.

Source: Author's own research, 2025

This result suggests that hospitals with environmental policies are significantly more likely to provide training or education to employees in the area of sustainability, compared to hospitals that do not have such policies or have only partially defined them. This result is supported by Bray et al. (2022) and Berniak-Woźny & Rataj (2023), who confirm that the systematic integration of environmental topics into the training and education of healthcare professionals is key to achieving long-term sustainability goals in healthcare. The fact that green training in hospitals has an impact on the achievement of environmental goals is also confirmed by studies (Ryan-Fogarty et al., 2016; Carino et al., 2021; Tisdall et al., 2025). Green management in hospitals has the potential to significantly improve environmental sustainability through employee training and education. However, to achieve maximum impact, it is necessary to implement standardized and systematic training programs, which many hospitals lack (Mcaleese et al., 2024). Vaishnavi & Suresh (2023) point to the need to implement an Environmental Sustainability (ES) program, where all employees, including doctors, nurses, and managers at all levels, are provided with specific training aimed at raising awareness of this issue.

Conclusions

The aim of this article was to analyze the state of green management in Czech hospitals, as literature research confirmed that hospital facilities are among the most energy-intensive facilities. Attention was focused on the size of the facility, the existence of an adopted environmental policy or strategy, energy savings, and employee training. The results showed that although larger hospitals more often declare the existence of an environmental policy, this relationship was not statistically significant. Similarly, no connection was found between the existence of an environmental strategy and active energy savings measures. However, a significant finding is that hospitals with a defined environmental policy more often provide training and education to employees in

the area of sustainability. This confirms the importance of green management in human resource management and underscores the need for systematic education as a tool for improving the environmental performance of healthcare facilities.

The novelty of the scientific findings in this study lies primarily in the connection between the concept of green management and human resource management in the context of healthcare organizations, which has been only minimally investigated in the Czech and European contexts. The study provides new empirical evidence that environmental policy can serve as a tool for developing employees' competencies in the area of sustainability, not just as a formal document. This approach expands current knowledge about the factors influencing the implementation of sustainable practices in the public sector, providing data for the creation of strategic frameworks and educational policies in healthcare. At the same time, the results complement international research by highlighting the specifics of the Czech context, where environmental management is still in its initial phase of systematic development.

Despite the correlations found, environmental management in healthcare in the Czech Republic remains underdeveloped and represents a significant research gap. Future research should focus on identifying barriers to the implementation of environmental policies and energy innovations, as well as on developing standardized training programs for employees at all levels. An emphasis on education, the introduction of modern technologies, renewable energy sources, and intelligent management systems can help hospitals reduce their environmental impact, strengthen their economic efficiency, and contribute to the achievement of sustainable development goals.

The limitation of this study is its regional scope, as the research was conducted only in the Czech Republic. Furthermore, the authors focused on formal environmental policies or strategies adopted by hospitals. It can be assumed that even smaller hospitals may think green without having an adopted policy. Future research could therefore examine whether informal sustainability practices exist in hospitals without formal strategies and whether the effectiveness of these practices varies depending on the size of the hospitals or regions.

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THE RELATIONSHIP OF CONTENT AND AFFILIATE MARKETING STRATEGIES WITH VARYING SHOPPING BEHAVIOURS*

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Abstract. This research analyses factors related to customers' variety-seeking shopping behaviour, including marketing analysis and online shopping motives. A key novelty of this study is the conceptualisation of effective marketing as a combined construct of content marketing and affiliate marketing, an approach not yet considered in prior research. This research paper also examines the role of customers' demographics within this relationship. With an experimental research design, a structured questionnaire was administered to a total of 408 participants, and the responses were examined through techniques of SEM, mediation, and moderation. The findings reveal that effective marketing, through affiliated content, stimulates customers' shopping motives and directly influences their variety-seeking behaviour. Moreover, demographic variables of customers moderate influence of effective marketing on variety-seeking behaviour, but not the mediated effect via online shopping motives. Retailers can capture variety-seeking behaviour by strategically delivering affiliated content that aligns customer motives with their market offerings.

Keywords: variety-seeking; shopping motives; marketing; demographics; content marketing; affiliate marketing

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JEL Classifications: M31, D12, D11, C38, L29

1. Introduction

The internet has revolutionised how individuals interact, access information, and engage in commerce, creating a pervasive digital environment that has redefined traditional marketing and consumer behaviour (Kaur et al., 2021; Išoraitė & Alperytė, 2024). In response, organisations are adopting innovative digital marketing strategies, particularly affiliate marketing and content marketing to influence consumer decision-making, foster engagement, and drive sales (Ahmad & Rosli, 2023). The global retail industry is projected to grow steadily, reaching a total retail sales value of approximately 32.8 trillion USD by 2026. From 2020 to 2024, the industry maintained an average growth rate of around 4.6%, indicating vigorous consumer purchasing activity. However, a notable slowdown is expected, with growth rates declining to 3.4% in both 2025 and 2026 (Bilzpalnr Team,

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2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/y3764249885

2025). This declining trend suggests the onset of market saturation and shifting consumer behaviour, highlighting the urgency of adopting innovative marketing strategies. Some organisations are struggling to survive with traditional marketing strategies that are out-of-date and challenging to keep pace with the current trends (Cannistrà et al., 2022; Cannistrà et al., 2024). Therefore, this study has conceptualised that adopting modern approaches such as affiliate marketing and content marketing can influence marketing strategies in the present time.

Content marketing is a method of developing and sharing valuable and appropriate content aimed at attracting, acquiring, and retaining a clearly-defined and understandable target audience, to generate customer profitability while fostering customer-brand relationship and fidelity (Lou & Xie, 2021). On the other hand, online affiliate marketing is a technique where an online retailer collaborates with and compensates third parties to increase their website traffic, ultimately promoting and selling their products and services (Snyder & Kanich, 2016). Additionally, consumers are regularly enticed to try new things or brands by special offers, discounts, or incentives in active marketing techniques, which leads to variety-seeking behaviour due to the perceived value and opportunity to examine other options (Dhar & Wertenbroch, 2000). Further, central to the success of these online marketing approaches is a deep understanding of customer shopping motives, which are broadly categorised into utilitarian and hedonic motivations, where utilitarian motives emphasise functionality, convenience, and cost-efficiency, while hedonic motives relate to emotional gratification, excitement, and social identity (Childers et al., 2001; Jaseckova, Konvit & Vartiak, 2022).

Nevertheless, the association between marketing and variety-seeking behaviour remains underexplored, limiting businesses' ability to craft strategies that cater to variety-seeking customers while maximising their outcomes. In this regard, the research problem is stated below.

2. Literature Review

Contextualise effective marketing of affiliate marketing and content marketing

In today's information-driven and trust-oriented marketing scenario, influencer marketing, along with customer reviews and brand awareness, shapes the customers' decision-making (Setyawanatra et al., 2025) because issues like spamming, security risks, cookie stuffing, privacy risks, and the lack of affiliate marketing are influencing the customers' attitude (Garg & Singla, 2024). Complementing the above facts, a study found that competency, integrity, organisation-based trust, knowledge-based trust, website reputation, and web interface design are the trust factors that shape the affiliate marketers' strength (Gregori et al., 2014). So, it can be said that the content of affiliate marketing influences the buying decision through brand image (Ibrahim & Suhermin, 2025).

In the marketing context, user-generated content positively influences customers' purchase intention, particularly when it has in-group and community acceptance (Sewwandi & Warnakulasooriya, 2025). The attributes of content, such as relevance, customer engagement, and trust, can significantly impact purchase intention and decision-making (Das et al., 2025; Meriem, 2025). However, the contents of influencers having a commercial flavour may adversely affect the customers' purchase intention (Lim et al., 2025). Thus, it requires conceptualisation and empirical testing to determine whether affiliate marketing and content marketing lead to effective marketing for retail organisations.

Effective marketing influences customers' variety-seeking shopping behaviour

As an essential element of digital marketing strategies, content plays a vital role in organically attracting and retaining customers (Fan & Zhang, 2025). So, content developed and promoted by brands for target customers can create value when it is both consumed and shared. However, creating content that aligns with a brand's core values is crucial for developing and promoting compelling content that drives a favourable impact (Ho, 2020). On the other hand, affiliate marketing is a successful internet marketing technique crucial for today's competitive market, showing significant growth alongside e-business development (Ivkovic, 2010) and is the most effective method of selling advertising space, offering greater flexibility, precise response measurement, enhanced revenue generation, and broader customer reach compared to traditional media. In addition, the tendency of customers to seek variety is an essential determinant of shopping values for buyers (Irani & Hanzaee, 2011), where the importance of separating variety switches from derived switches, along with consideration of the

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/y3764249885

product's category-level aspects, explains the occurrence of variety-seeking shopping behaviour. Moreover, in the green context, affiliate marketing & content marketing drive variety-seeking behaviour, with consumer motives serving as a mediator (Sahu et al., 2025). The above points imply that both content and affiliate marketing collectively influence the variety-seeking behaviour of customers.

H1: ***Effective marketing is significantly and positively influencing their variety-seeking shopping behaviour.***

Effective marketing influences customers' online shopping motives

Content formed and promoted by brands for target customers can create value when it is both consumed and shared. For this, the creation of content needs to align with the core values of brands and value creation to develop and promote compelling content that drives favourable impact (Ho et al., 2020). Furthermore, service features and affiliate marketing, to a certain extent, positively impact the buying interest of electronic commerce consumers (Marquerette & Hamidah, 2023). Specifically, informativeness, perceived trust, usefulness and incentives are significant drivers that influence customers' attitudes toward affiliate marketing. Moreover, people engage in shopping for purposes beyond merely fulfilling their product or service needs. These motivations behind shopping trips can vary and may include factors unrelated to making a purchase, where utilitarian and hedonic motivations substantially affect searching for information online and intentions to shop, which in turn is a significant predictor of intention to shop online (Fülöp et al., 2023). Further, online shopping positively influences consumer loyalty, yet it requires support from content marketing and discounts in price to capture customers' interest. However, customers' pleasure slightly reduces the impact of content marketing on online shopping, although the effect is not statistically significant (Halik & Nugroho, 2022). From the above points, it thus becomes necessary to examine the relationship between marketing and online shopping motives.

H2: ***Effective marketing is significantly and positively influencing their online shopping motives.***

Online shopping motives lead to variety-seeking shopping behaviour

Shopping motivations differ across channels and types of products, with online buyers valuing savings, variety, and delivery, while in-store buyers seek socialising and individualised assistance. Further, online shopping offers convenience and instant gratification; in-store shopping provides nostalgia and loyalty benefits. For hedonic products, shoppers value self-confidence and the in-store experience. At the same time, utilitarian purchases prioritise control across both channels (Haridasan & Fernando, 2018), where both utilitarian and hedonic motivations influence online information-seeking as well as intention of buying, while the information search plays a crucial role in customers' intention of online purchase (Fülöp et al., 2023). Further, the utilitarian motivation of online purchasing is categorised into five dimensions, which are accessibility, information availability, convenience, searchability and product availability (Kumar & Kashyap, 2018). Moreover, the extent of information seeking about the product and deal-proneness acts as a mediating factor, further shaping the relationship between variety-seeking behaviour and shopping orientation (Murray, Jin & Martin, 2022). Thus, it is crucial to comprehend the association between online shopping motives and variety-seeking shopping behaviour.

H3: Online shopping motives are significantly and positively influencing their variety-seeking shopping behaviour.

The interrelationship between effective marketing, online shopping motives, and variety-seeking behaviour

Amid the intense global competition, companies are increasingly implementing e-commerce and online business strategies that leverage social media networks and digital platforms to gain deeper insights into consumer behaviour, strengthen marketing strategies, and share innovative business information (Rosário & Raimundo, 2021). One of these e-commerce strategies is content marketing, which uses internet celebrity endorsement to drive referral traffic to e-commerce websites effectively; however, its impact on sales growth remains limited (Iliescu, & Ioanid, 2024). Another e-commerce strategy, affiliate marketing, has a positive and significant influence on buying intention and consumer behaviour; however, its impact on shopping decisions remains positive yet negligible (Kertiriasih, 2023). Moreover, customers' desired values play a crucial role than their prior experiences in shaping intentions of variety seeking, with their satisfaction and anticipated utilitarian or hedonic values influencing these intentions differently across high and low allocentric personality groups

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/y3764249885

(Ha & Jang, 2013). Thus, the tendency to seek variety is a critical factor in shopping values for shoppers. However, there is an adverse association between hedonic value and and price sensitivity, whereas there is no evidence of a favourable relationship between utilitarian value and price sensitivity (Irani & Hanzaee, 2011).

H4: ***There is a significant indirect positive effect of 'effective marketing' on 'variety seeking shopping behaviour' through the mediation of the online shopping motive of customers.***

The role of customers' demographics in effective marketing, online shopping motives, and the variety-seeking shopping behaviour framework

Customers' attitude towards the promotional strategies of the mall retailers is influenced by price sensitivity, shopping value, and proneness towards deals and coupons, where customers' demographic variables, such as age, income, and education, impact their attitude towards promotions. In addition to this, the variations in demographic factors shapes perceptions of customers regarding affiliate-marketing strategies; these strategies are associated with their decision-making processes in online shopping, which in turn are closely linked to their digital shopping behavior (Išoraitė, 2024) where gender, age, and income are significantly associated with risk factor, product (or brand) knowledge, feed-backs, and product value of affiliate marketers (Xu et al., 2025). Moreover, customers' explorative behaviour, type of the product, past purchasing patterns, gender and breadth of available choices significantly predict customers' variety-seeking behaviour (Jankalová & Vartiak, 2017; Ni et al., 2025).

Furthermore, the scarcity of information substantially increases the extent of variety-seeking, as customers' expertise levels are shaped by acquiring information through learning and experience, thereby moderating this link. However, novice customers are more prone to seek variety than expert customers when information availability is limited. Therefore, it becomes necessary to examine the role of customers' demographics within this intricate relationship among effective marketing, online shopping motives and variety-seeking shopping behaviour.

H5: ***Customers' demographic variables are significantly interacting with the effective marketing, shopping motives and variety seeking shopping behaviour.***

3. Theoretical grounding for major hypotheses

Assael's (1987) framework of classification of buying behaviours suffers multi-dimensional shortcomings to explain all the types of buying behaviours of customers in the modern content driven competitive markets, particularly in the recent social complexity. It does not fully capture the nuances of the complex buying behaviour, dissonance reducing buying behaviour, habitual buying behaviour, and variety-seeking buying behaviour. This framework mostly driven by the consumer-actions and does not capture market stimuli (affiliated contents) that may ease or deviate buying behaviour of consumers. Also, it does not consider the psychological drive (motive) that variate the consumer's involvement in purchase decision. Our study addresses these lacunas by modifying the Assael's framework of classification of buying behaviour, supported by empirical evidences. The Assael's framework is based on two dimensions that are difference between brands and buyer involvement. In our study, we intend to classify the buyer involvement on two dimension that are affiliated contents (marketing effectiveness as second order construct in this study) and shopping motives, as both dimensions are highly relevant in modern customers' life style.

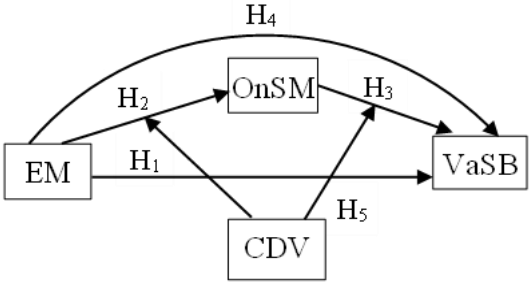


Figure 1. Theoretical framework and hypotheses
Source: own processing

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
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This study's theoretical framework (Figure 1) reflects five major hypotheses and four constructs, such as Effective marketing (EM), online shopping motive (OnSM), variety seeking shopping behaviour (VaSB), and customers' demographic variables (CDV).

4. Study's Design and Methodology

Problem Statement
Does the variety-seeking shopping behaviour derive from underlying shopping motives, within the realms of affiliate marketing and content marketing?

Objectives:

1. To identify and define the significant dimensions of affiliate marketing and content marketing.
2. To analyse the relationship among affiliate marketing, content marketing, and shopping motives with variety-seeking shopping behaviour.
3. To explore the role of customers' demographics within the relationship of affiliate marketing, content marketing, shopping motives and variety-seeking shopping behaviour.
4. To develop marketing strategies that cater to variety-seeking customers while maximising the businesses' outcomes.

This research paper employs an experimental research design in which causal associations between effective marketing (affiliate-marketing and content-marketing), "online shopping motives" and "variety-seeking shopping behaviour" are investigated. A systematically developed questionnaire employing a five-point Likert measurement scale is administered to 408 participants. This questionnaire contains 41 items, from which 10 items are related to effective marketing; 18 items are related to the online shopping motives; 8 items are related to variety-seeking shopping behaviour, and five items are related to customers' demographics. This study implemented a stratified sampling method, with four geographical areas treated as four strata. The analysis of data starts with scale reliability testing. Then the analysis is carried out using structural equation modelling (SEM), where two measurement models that are online shopping motives with four constructs and effective marketing with two constructs are tested using confirmatory factor analysis before testing the structural model to make sure that the constructs can be measured by the indicators derived from the literature review. Thus, the second-order CFA is applied. After which, the moderating effect of customers' demographics is tested within the above-mentioned structural relationship. Hence, the present study intended to test Hayes' model-59. The data analysis is performed using software such as IBM SPSS 27.0, AMOS 24.0, Process-Macro, and Mendeley Desktop for referencing and citations.

5. Analysis, Results and Discussion

Study's Scale-Reliability
The reliability of this study's scale, as measured by internal consistency, is nearly 84% (Cronbach's Alpha value with standardised items is 0.844), comprising 41 items that include five demographic variables. So, the structured questionnaire carries 'desirable' reliability along with having a mean value of 167.15 and corresponding standard deviation value of 18.554.

Sample profile of the study
The sample consists of nearly 67% males and 33% females. The sample's age distribution shows that the majority, around 46%, are young customers (up to the age of 30), while middle-aged customers (up to the age of 50) comprise 50%. The older generation (above 50 years) makes up only 4%. The marital status shows that around 49% are unmarried, while the married individuals constitute 49%, and only 2% are divorced. Among the sample, participants having an education qualification of intermediate level are only 11%, undergraduate level 17%, post-graduate level 39%, and nearly 33% of respondents carry a qualification higher than post-graduate level, where the sample's income level reveals that the low-income category (up to 30,000 INR) accounts for nearly 51%, the mid-income category (up to 60,000 INR) for 31%, and the high-income category (above 70,000 INR) for 18%.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/y3764249885

Measurement model of online shopping motives (OnSM)
This measurement model is tested through CFA that has four constructs: VS (Variety-seeking); IUPS (Information use in planning and shopping); PSC (Physical store characteristics), and OC (Overall Convenience), carrying five, four, four, and five indicators, respectively.

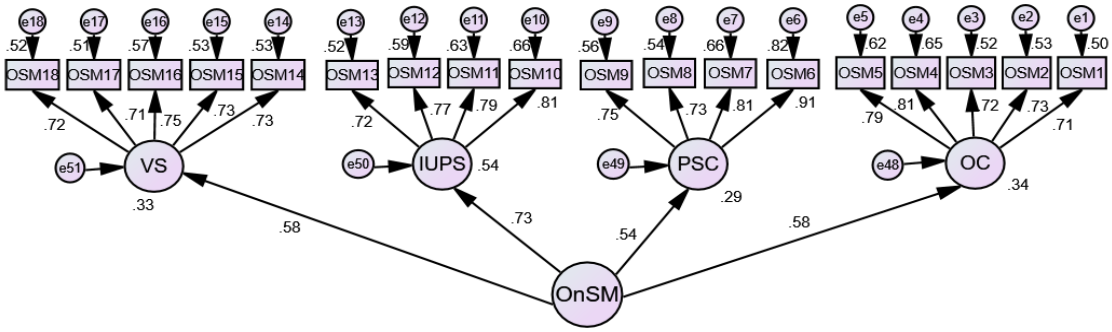


Figure 2. Measurement model of online shopping motives

Source: own processing

Model-fitting of OnSM is acceptable with its statistical inferences that fit-indices are crossing (or fall below) the recommended values, where values (.966, .960, and .966) of IFI, TLI and CFI are higher than .95 (Hu & Bentler, 1999; Hair et al., 2013); values of GFI, NFI and RFI are more than .9 (Hu & Bentler, 1998); value (1.950) of CMIN/DF is below 3 (Schreiber et al., 2006); value (.042) of RMR is lesser than.08 (Hu & Bentler, 1999); and the value of RMSEA (.048) is below.06 (Hu & Bentler, 1999).

Measurement model of Effective marketing (EM)
CFA tests this measurement model with two constructs, which include effective Affiliate marketing (AME) and Content marketing (CME), carrying five and five indicators, respectively.

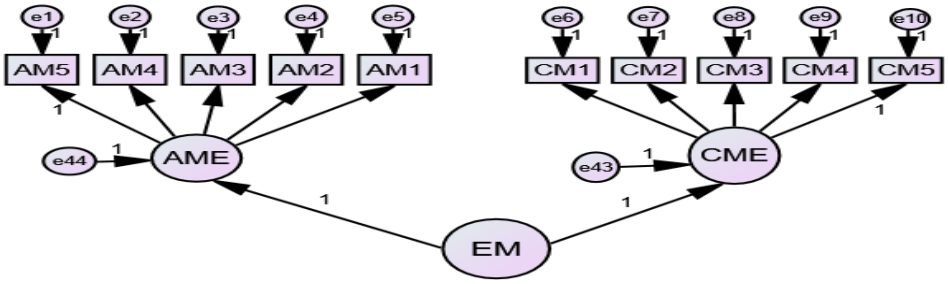


Figure 3. Measurement model of Effective marketing

Source: own processing

Statistical inferences say that model-fitting of EM is acceptable as fit indices are meeting the cut-off criteria, where values (.968, .958, .968, .950, and .958) of IFI, TLI, CFI, NFI and GFI are higher than .95 (Hair et al., 2013; Hu & Bentler, 1999); Values (.934) of RFI is higher than .9 (Hu & Bentler, 1998); value (2.700) of CMIN/DF is below 3 (Schreiber et al., 2006); value (.044) of RMR is lesser than.08 (Hu & Bentler, 1999); and the value (.064) of RMSEA is between.06 and.08 (Schreiber et al., 2006).

Reliability and convergent validity of both measurement models (OnSM and EM)
Every construct (VS, IUPS, PSC and OC; AME and CME) of both measurement models is tested for convergent validity & reliability according to the recommendations of Straub et al. (2004), and Table 1 illustrates the results.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/y3764249885

Table 1. Convergent Validity and Reliability of constructs of both OnSM and EM

Online Shopping Motives (OnSM)							
Indicators with respective constructs	B	't'	α and CR	Indicators with respective constructs	B	't'	α and CR
OC				IUPS			
OSM1	.704	14.354*	.865 and .865	OSM10	.808	14.653*	.856 and .856
OSM2	.726	14.972*		OSM11	.794	15.175*	
OSM3	.720	14.874*		OSM12	.771	14.149*	
OSM4	.806	17.090*		OSM13	.719	---	
OSM5	.791	---					
PSC				VS			
OSM6	.908	17.907*	.876 and .879	OSM14	.727	13.508*	.850 and .850
OSM7	.814	16.728*		OSM15	.730	13.587*	
OSM8	.733	14.990*		OSM16	.750	13.937*	
OSM9	.750	---		OSM17	.712	13.390*	
				OSM18	.727	---	
Effective marketing (EM)							
AME				CME			
AM1	.703	13.050*	.848 and .848	CM1	.758	13.980*	.854 and .854
AM2	.724	13.411*		CM2	.704	13.077*	
AM3	.758	13.969*		CM3	.728	13.493*	
AM4	.738	13.652*		CM4	.773	14.223*	
AM5	.714	---		CM5	.709	---	
OnSM (2nd order construct)				**EM (2nd order construct)**			
OC	.581	6.561*	.740				
PSC	.543	5.753*					
IUPS	.733	6.181*		AME	.829	---	.841
VS	.577	---		CME	.781	---	

't' is the value of the critical ratio (CR); β – Standardised regression weight; α – Cronbach's Alpha; OC: Overall Convenience; PSC: Physical Store Characteristics; IUPS: Information use in Planning and Shopping; VS: variety-Seeking; AME: Affiliate Marketing; CME: Content Marketing; *Significant at 1% level of significance; --- regression weight is pre-fixed as 1

Source: Authors' compilation from analyses

Values of Cronbach's Alpha and composite reliability (CR) for each construct exceed .7, as suggested by Hair et al. (2013), indicating acceptable reliability for both measurement models. Simultaneously, convergent validity is also permissible for these two measurement models having additional statistical results of lowest factor-loadings (.728, .734, .709, .711, .707, .730) of the constructs (VS, IUPS, PSC and OC; AME and CME) of OnSM and EM, respectively, that crosses 0.7 (Henseler et al., 2009); and all AVE values that cross 0.5 (Bagozzi & Yi, 1988), by meeting the cut-off values. A significant 't' for every indicator at 1% level of significance proves the correctness of the model composition (Table 1). The values (0.848 and 0.854) of CR and the value (0.528 and 0.540) of AVE of AME & CME (measurement model of effective marketing) are higher than the prescribed (Hair et al., 2013) value, respectively.

Discriminant validity of both measurement models (OnSM and EM)

All six constructs of both measurement models are tested for discriminant validity, and results are presented in Table 2.

Table 2. Discriminant validity of constructs of OnSM

Constructs OnSM	**Mean**	**SD**	**AVE**	**MSV**	**ASV**	**Max R(H)**	**OC**	**PSC**	**IUPS**	**VS**
OC	19.26	4.235	.563	.168	.137	.870	.751			
PSC	15.02	3.322	.647	.197	.116	.901	.296	.804		
IUPS	15.40	3.163	.599	.197	.174	.860	.393	.444	.774	
VS	18.92	3.984	.532	.170	.134	.851	.410	.253	.412	.729
Discriminant validity of constructs of EM										
AME	18.05	4.315	Values (0.726 and 0.734) of the square root of AVE are greater than the value (0.648) of inter-construct co-relationship.							
CME	17.89	4.351								

SD: Standard Deviation, AVE: Average Variance Extracted; MSV: Maximum Shared Variance; ASV: Average Shared Variance; OC: Overall Convenience; PSC: Physical Store Characteristics; IUPS: Information Use in Planning and Shopping; VS: Variety-Seeking. *Inter-construct co-relationship is significant at 1% level of significance.

Source: Authors' compilation from analyses

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2025 Volume 13 Number 2 (December)
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Discriminant validity of every construct is justified as the square root of AVE (diagonal values in bold) for every construct (Table 2) of online shopping motives carries a higher value than the respective inter-construct co-relationships; and values of MSV and ASV are less than respective values of AVE (Fornell and Larcker, 1981). Additionally, the values of Max R(H) and the maximal reliability of all constructs are more than 0.8 (Hancock and Mueller, 2001). The desired statistical nature of all constructs is reflected in their mean and standard deviation (SD). For the construct of Effective marketing (EM), the values (0.726 and 0.734) of the square root of AVE are greater than the value (0.648) of inter-construct co-relationship, which justifies successfully passing the discriminant validity criteria (Fornell & Larcker, 1981).

Structural model analysis

Along with the two-step recommendation (Anderson & Gerbing, 1988), the structural model (Figure 3) is tested by the SEM (Structural Equation Modelling) technique after testing two measurement models. The structural model carries 18 indicators of OnSM, 10 indicators of EM, and eight indicators of VaSB.

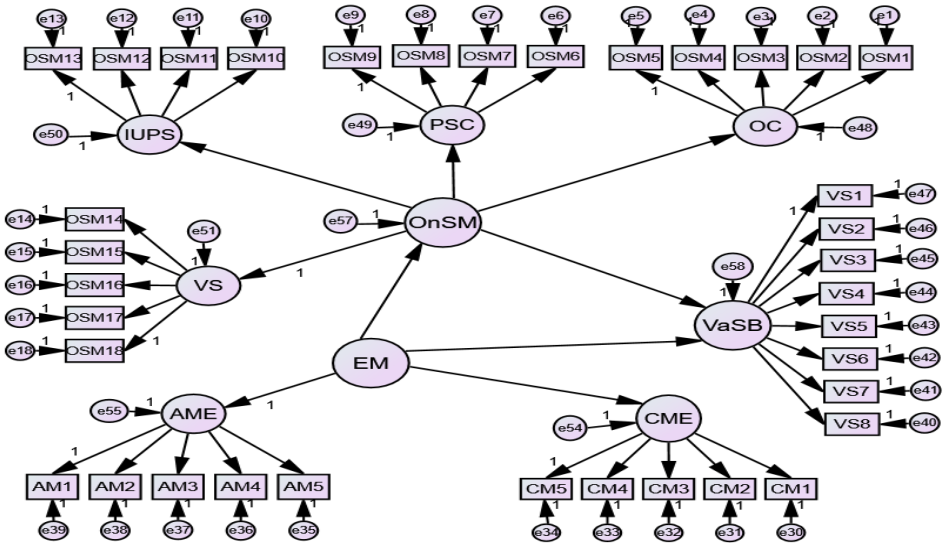


Figure 4. Structural model of variety-seeking shopping behaviour on effective marketing and online shopping motives

Source: own processing

Structural model is adequately fitting to the data and concept as major fit-indices are successfully meeting the cut-off criteria, where values (.903, .958, .955, .958) of GFI, IFI, TLI and CFI are more than .9 (Hu & Bentler, 1998); value (1.442) of CMIN/DF is below 3 (Schreiber et al., 2006); value (.058) of RMR is below .08 and value (.032) of RMSEA is below .06 (Hu & Bentler, 1999). Thus, three major hypotheses (H1, H2 and H3) are tested through the above structural model, and the results are explained in Table 3. Standardised regression weights shown in the model (Figure 4) justify their effects as being significant for the hypotheses.

Table 3. Results of testing of the structural model and major hypotheses

Major hypotheses in the structural model	B	S.E.	't'	Hypothesis testing results
Effective marketing is significantly and positively influencing their variety-seeking shopping behaviour. (H_1: VaSB ← EM)	.271	.082	3.124**	Supported
Effective marketing is significantly and positively influencing their online shopping motives. (H_2: OnSM ← EM)	.234	.048	2.941**	Supported
Online shopping motives are significantly and positively influencing their variety-seeking shopping behaviour. (H_3: VaSB ← OnSM)	.219	.115	3.024**	Supported
OnSM: Online Shopping Motives; EM: Effective Marketing; VaSB: Variety-Seeking Shopping Behaviour; β-Standardised Regression Weight; 't' – Critical Ratio; S.E.- Standard Error; **Significant at 5% level of significance.				

Source: Authors' compilation from analyses

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2025 Volume 13 Number 2 (December)
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Table 3 reflects that three major hypotheses are supported. That means the green perception of customers has significant positive effects (nearly 47% and 93%) on their purchase intention and on their attitude toward sustainable practices. And, attitude toward sustainable practices also carries a significant positive (nearly 52%) effect on their purchase intention. Three hypotheses are logically supporting the 4th hypothesis (H4) that the indirect impact (through the mediating effect of attitude toward sustainable practices) of green perception on purchase intention is significant.

Moderating effects of demographic variables within the structural model

Hypothesis 5 (H5) is tested through moderation analysis, where five demographic variables (gender, marital status, age, educational qualifications and gross income) are treated as moderators within the structural relationship of EM, OnSm, VaSB. It is tested through model-59 of Hayes (2018), and the statistical results, along with inferences, are systematically presented as follows.

Table 4. Significance of the moderating effect of demographic variables

	Moderators	**Interac-tions**	**Coeef-icient**	**SE**	**'t'**	**LLCI**	**ULCI**
The target variable is VaSB (Variety seeking shopping behaviour); The causal variable is EM (Effective marketing). Mediator is OnSM (Online Shopping motive)	Gender	Int_1	-.2251	.1110	-2.0284**	-.4433	-.0070
		Int_2	.8876	.1702	5.2161*	.5531	1.2221
	Marital Status	Int_1	-.2584	.1104	-2.3404**	-.4754	-.0414
		Int_2	.9440	.1676	5.6307*	.6144	1.2735
	Age	Int_1	-.0544	.0219	-2.4877**	-.0974	-.0114
		Int_2	.2466	.0346	7.1181*	.1785	.3147
	Educational Qualification	Int_1	-.1423	.0587	-2.4238**	-.2577	-.0269
		Int_2	.5351	.0869	6.1614*	.3644	.7058
	Income	Int_1	- .0377	.0177	-2.1250**	-.0726	-.0028
		Int_2	.1992	.0269	7.4154*	.1464	.2520
S.E.: Standard error, LLCI: lower-level confidence interval, ULCI: upper-level confidence interval, level of all confidence intervals is 95.0000, No. of bootstrap samples is 5,000; **significant at 0.005; *significant at 0.001, Int_1: EM x Separate demographic variables, Int_2: OnSM x Separate demographic variables							

Source: Authors' compilation from analyses

Table 4 indicates that both Int_1 and Int_2 are significant for all five moderators at the 5% and 1% significance levels, respectively (Hayes, 2018). However, the Int_1 is substantial on the minus side for all moderators. Furthermore, the values of both LLCI and ULCI in all cases are either negative or positive, implying the significance of the moderating effect. The above results justify that all five moderators are significantly moderating the structural relationship of EM, OnSM and VaSB.

Table 5. Demographic variables are moderating effects of EM on VaSB

	Moderators	**Effect**	**S.E.**	**'t'**	**LLCI**	**ULCI**
Conditional direct effects	Gender (1, 2)	.3871	.0791	4.8937*	.2316	.5426
		.1620	.0779	2.0803**	.0089	.3150
	Marital Status (1, 2)	.4161	.0791	5.2606*	.2606	.5715
		.1576	.0770	2.0462**	.0062	.3091
	Age (2, 4, 6)	.4092	.0692	5.9131*	.2732	.5453
		.3004	.0508	5.9123*	.2005	.4003
		.1916	.0648	2.9552**	.0641	.3190
	Educational Qualification (1, 2, 4)	.3448	.0577	5.9724*	.2313	.4582
		.3448	.0577	5.9724*	.2313	.4582
		.2025	.0636	3.1847**	.0775	.3274
	Income (1, 3, 4)	.3773	.0652	5.7902*	.2492	.5054
		.3019	.0507	5.9541*	.2022	.4016
		.1888	.0691	2.7306**	.0529	.3247
Conditional indirect effects (OnSM is the Mediator)	Gender (1, 2)	**Effect**	**BootSE**	**BootLLCI**	**BootULCI**	
		.0029	.0098	- .0096	.0314	
		.1402	.0424	.0632	.2272	
	Marital Status (1, 2)	.0024	.0108	- .0129	.0314	
		.1492	.0440	.0685	.2407	

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2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/y3764249885

	Age (2, 4, 6)	.0075	.0179	- .0214	.0050
		.0149	.0115	- .0014	.0424
		.1353	.0384	.0648	.2144
	Educational Qualification (1, 2, 4)	.0021	.0072	- .0069	.0227
		.0021	.0072	- .0069	.0227
		.1085	.0311	.0514	.1740
	Income (1, 3, 4)	.0057	.0157	- .0180	.0460
		.0090	.0105	- .0064	.0354
		.1697	.0463	.0837	.2650
VaSB: Variety seeking shopping behaviour; EM: Effective marketing; OnSM: Online shopping motive; S.E.: Standard error, LLCI: lower-level confidence interval, ULCI: upper-level confidence interval; level of confidence for all confidence intervals is 95.0000, No. of bootstrap samples is 5,000; *significant at 0.001; **significant at 0.005					

Source: Authors' compilation from analyses

Table 5 reflects that both the direct effect (with five demographic variables as moderators) and the conditional indirect effect are significant (Hayes, 2018). The conditional direct effects are substantial, along with all positive values for LLCI and ULCI. The conditional indirect effects are substantial, with positive values of BootLLCI and BootULCI at higher levels of moderators. However, this is insignificant at lower levels of respective moderators, as the values of BootLLCI are negative and BootULCI are positive. Hence, it can be concluded that conditional indirect effects are not significantly moderating, but conditional direct effects are significantly moderating.

Although the structural relationship of EM, OnSM and VaSB is significantly moderated by five demographic variables (gender, marital status, age, educational qualifications and gross income), the moderated conditional indirect effect of EM on VaSB through OnSM is not proven. On the other hand, the above-mentioned demographic variables significantly moderate the direct impact of EM on VaSB.

Testing the standard method bias

Harman's (1967) recommendation states that a single component (or factor) should not account for more than 50% of the total variance in the study's data when undergoing unrotated principal component analysis with a pre-fixed single factor. This study indicates that the measuring-technique bias is negligible, as all 36 variables of the structural model account for 19% (Total percentage of factor loading extracted = 19.029) of the variance.

5. Findings

Retail organisations operating in today's digital marketplace can enhance effective marketing through affiliate and content marketing, with affiliate marketing showing a slightly more substantial influence. Online shopping motives, including information use, variety-seeking, convenience, and store characteristics, significantly strengthen customer engagement, with information use being the most essential factor. Effective marketing achieved through affiliated content directly and positively affects customers' variety-seeking shopping behaviour and indirectly through their shopping motives. Moreover, demographic factors—gender, age, income, education, and marital status—moderate this direct relationship but not the mediated one.

Empirical evidence supports the study's modification of Assael's (1987) buying behaviour framework. The revised model introduces two key dimensions—affiliated content (effective marketing) and shopping motives—within customer involvement. As both of the above-mentioned dimensions empirically show a significant influence with similar magnitude on the variety-seeking buying behaviour (Figure 4), 'customer-involvement' dimension (horizontal axis) should carry 4 levels in the modified classification-matrix (Figure 5). Vertical axis for the modified matrix is considered to be same as the Assael's classification. The difference between brands is a reality of marketers, where there is no role of customers. Therefore, we have not considered the vertical axis for modification. However, the dimension of customer involvement in horizontal axis, directly is concerned with customers. Hence, the horizontal axis is modified into four levels, addressing both subjective (shopping motives) and objective (affiliated contents) aspects of buyer's involvement. The modified matrix identifies eight distinct types of buying behaviours, combining levels of involvement and brand differentiation.

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→ Difference between brands →					
	Significant difference in brands	Solution- oriented complex buying behaviour	Enjoyable complex buying behaviour	Variety seeking buying behaviour	Variety referral buying behaviour
	Low difference in brands	Learning-based dissonance reducing buying behaviour	Action-based dissonance reducing	Habit building buying behaviour	Habit driven buying behaviour
		Content oriented **high** involvement	Motive oriented **high** involvement	Content oriented **low** involvement	Motive oriented **low** involvement
	→ Buyer involvement →				

Figure 5. Octagon buying behaviours

Source: Prepared by the authors extending the Assael's classification of buying behaviours

Addressing the drawbacks of Assael's (1987) classification of buying behaviour, it is inferred (figure-5) from the empirical outcomes of this study that high participation and strong motives produce enjoyable, complex buying behaviour, while high involvement with content orientation results in solution-oriented behaviour. Low involvement and motive orientation lead to habit-driven behaviour, whereas low involvement with content orientation forms habit-building behaviour. When brand differences are significant but involvement is low, consumers exhibit either variety-seeking or variety-referral behaviour, depending on their orientation. Under low brand differences and high participation, customers exhibit action-based or learning-based dissonance-reducing behaviour.

Affiliated content can effectively influence shopping motives by showcasing product variety, convenience, and positive store experiences. Retailers should stimulate customers' shopping motives through credible, socially endorsed information and align offerings with variety-seeking tendencies. Marketing functions must strategically use affiliated content to direct these motives and behaviours. Retailers unable to customise for specific demographics should employ indirect approaches via shopping motives, while those with adequate resources should directly target variety-seeking behaviour through enhanced effective marketing.

6. Conclusions

How retail organisations should manage the variety-seeking shopping behaviour of customers remains unanswered to date. But this study intended to answer this mystery convincingly. Thus, this study explores the relationship among effective marketing, online shopping motives, customers' demographics, and variety-seeking shopping behaviour. To date, these intricate relationships have not been empirically validated, making their investigation more essential and timelier, which this paper addresses.

This research work confirms that affiliate marketing and content marketing are pivotal in enhancing the effective marketing of retail organisations. The empirical evidence further reveals that effective marketing has a direct and positive influence on variety-seeking behaviour and online shopping motives, which in turn positively influences variety-seeking shopping behaviour. Further, customer demographics moderate the direct path but do not moderate the indirect path.

Beyond filling a gap in the literature, this research contributes valuable, actionable implications for retailers. The retailers, by leveraging content and affiliate marketing, can stimulate online shopping motives of customers and cater for their variety-seeking tendencies. This, in turn, can help retailers craft appropriate strategies that align with diverse customer segments.

Although this study considers a new dynamic of the modern information market, incorporating more relevant elements beyond affiliate and content marketing could further accommodate the dynamism of the contemporary competitive market. Shopping motives in the online context are studied here, but the customers' motives in both online and in-person contexts can provide in-depth strategic orientations for retail organisations. Although demographic variables are essential moderators, future researchers can address socio-psychological properties such as risk perception, cultural background, and habits.

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BRIDGING GLOBAL AND EUROPEAN AGENDAS: AN EVALUATION OF PROGRESS ON SDG 4 AND THE EUROPE 2020 STRATEGY*

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Abstract. This paper evaluates the progress of the European Union in meeting the educational objectives defined by the Europe 2020 strategy and the 2030 Agenda for Sustainable Development, with a particular focus on Sustainable Development Goal 4 (SDG 4). The analysis concentrates on two key indicators: the share of individuals leaving education and training early and the proportion of the population with completed tertiary education. Using Eurostat data, the study first assesses the achievement of national targets by EU member states up to 2020 and then compares these outcomes with the 2030 targets. The research applies descriptive statistical methods complemented by regression analysis to estimate future developments up to 2030. Results confirm that while the EU as a whole already surpassed the 2020 benchmark for early school leavers, persistent disparities remain across member countries. The regression findings suggest that, assuming current trends continue, the EU is likely to reduce early school leaving below 9% by 2026. In parallel, the 45% target for tertiary education attainment could be achieved by 2027. However, country-specific gaps reveal uneven progress, particularly in Romania, Spain, and Germany, while states such as Greece, Croatia, Ireland, and Luxembourg demonstrate strong performance. The results highlight the central role of education as both a driver and a consequence of sustainable economic growth, labor market competitiveness, and social cohesion. At the same time, they underscore the importance of consistent policy efforts across member states to address structural inequalities and ensure convergence toward the 2030 Agenda goals.

Keywords: sustainable development; Europe 2020; SDG 4; early leavers from education; tertiary education

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JEL Classifications: I23, I24, I25

1. Introduction

Education is a key pillar of sustainable development and social progress. Within the framework of the 2030 Agenda for Sustainable Development, this dimension is addressed in Sustainable Development Goal 4 (SDG 4), which emphasizes the need to ensure inclusive and equitable quality education and to promote lifelong learning opportunities for all (United Nations, 2015). This target reflects the close link between the educational attainment of the population, economic competitiveness, and social cohesion.

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2025 Volume 13 Number 2 (December)
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In the European context, SDG 4 builds on the priorities expressed in the Europe 2020 strategy (European Commission, 2010), which aimed to promote smart, sustainable, and inclusive growth. One of the key indicators in this strategy was the reduction of the share of people leaving education and training early, as well as the increase in the share of the population with completed tertiary education. These measures were intended to strengthen human capital, increase employability, and reduce the risk of social exclusion.

The link between the global goals of the 2030 Agenda and European policy thus points to the long-term importance of investing in education, which is not only an individual right but also a fundamental prerequisite for economic and social development.

The main aim of this paper is, therefore, to evaluate and analyze the progress in fulfilling the educational targets within the European Union, as defined by the Europe 2020 strategy and further developed in the 2030 Agenda for Sustainable Development (SDG 4), and to project the possible future development of the monitored indicators up to 2030.

2. Theoretical background

The interconnection between the global agenda for sustainable development and the European Union's education strategies represents a key framework for assessing progress toward Sustainable Development Goal 4 (SDG 4) – quality education for all. Numerous scholars have analyzed this goal within the context of European educational policy and its linkage to the economic and social objectives of the Europe 2020 strategy.

According to Aleksandra Pleśniarska (2019), European institutions have long sought to align the implementation of the 2030 Agenda with their own development frameworks. The author notes that although positive trends are evident in tertiary and lifelong education, significant disparities remain among EU member states. Gender-based inequalities in educational attainment and graduate employability demonstrate that the Union has not yet fully achieved its 2020 objectives. Momete and Momete (2021) expanded this discussion by proposing a framework for measuring progress in Education for Sustainable Development (ESD) across EU countries. Their research resulted in a composite index that enables comparison of member states' performance in achieving SDG 4 and identification of best practices. Boeren (2019) approaches the issue from micro, meso, and macro-level perspectives, emphasizing the need to integrate individual, institutional, and governmental dimensions in achieving SDG 4.

At the global level, Durrani et al. (2023) examined how the COVID-19 pandemic affected progress toward SDG 4 through a case study of Kazakhstan. Their findings correspond with those of Gunawan (2025), who highlights that socio-economic, geographical, and digital divides exacerbate educational inequalities. Both authors conclude that the pandemic exposed not only technological and infrastructural weaknesses but also deep-rooted social disparities that hinder advancement toward quality education. Building on these insights, Sáenz-Rico de Santiago and Mendoza Carretero (2023) stress the need, in the European context, to integrate economic, social, and environmental dimensions of sustainable development into educational strategies.

Equality of access and inclusive education represent another key thematic dimension. Ramtohul (2024) emphasizes that the core objective of SDG 4 is not only to ensure accessibility but also to guarantee equal opportunities for acquiring knowledge and skills. Reinders, Dekker and Falisse (2020) add that inequalities in higher education cannot be explained solely by financial factors - sociocultural determinants play an equally decisive role. This perspective is further developed by Verma et al. (2025), who argue that higher education institutions can contribute to reducing social inequalities through their research and educational activities, thereby supporting the achievement of both SDG 4 and SDG 10.

The role of higher education as an instrument of sustainable growth is reflected in the work of Popelo et al. (2023), who analyze the contribution of EU universities to implementing sustainability principles. Hara (2025) extends this discussion to ASEAN countries, where insufficient digital infrastructure and unequal access to education constrain economic development. An empirical contribution is provided by Saini, Sengupta, Singh et

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/e6532399867

al. (2023), who use a genetic algorithm to analyze the interconnections among SDG 4 indicators and emphasize the necessity of adopting a comprehensive and systemic approach to education policy.

A concluding perspective is offered by Edwards, Asadullah, and Webb (2024), who assess mid-term progress of the 2030 Agenda and underline the persistent gaps between declared goals and achieved outcomes. Ritzen and Zomerplaag (2025) add a European dimension to this debate, highlighting the need for structural reforms, stronger investment in innovation capacity, and enhanced regional cohesion to maintain the EU's competitiveness in a rapidly changing world.

Despite regional differences and the variety of methodological approaches, scholars generally agree that quality and inclusive education constitute a fundamental prerequisite for sustainable development, social justice, and economic prosperity. The alignment of the global SDG 4 agenda with regional strategies, such as Europe 2020, therefore remains an essential condition for achieving a balanced and equitable education system.

The review of relevant scholarly literature suggests that while there is a significant body of studies focused on the retrospective evaluation of the educational goals of the Europe 2020 strategy, most of them primarily use descriptive analysis to assess progress up to 2020. These works effectively map the achieved status and identify both successful and lagging member states. The key research gap in the current literature lies in the lack of a comprehensive quantitative analysis that would systematically link the evaluation of Europe 2020 strategy target achievement with a prediction of the dynamics of change in relation to the new goals of the 2030 Agenda (SDG 4). Specifically, existing research rarely employs inferential statistical methods (such as regression trend analysis) for projecting future development towards the 2030 targets, particularly for each individual EU Member State. Our study aims to fill this gap. By applying descriptive and regression analysis to currently available Eurostat data, we will not only evaluate the progress achieved up to 2020 (in line with RQ1) but also estimate whether the current rate of change will allow the EU and its member states to meet the more ambitious targets set for 2030 (in line with RQ2).

3. Methodology

The methodology of this paper is based on a quantitative analysis of statistical data aimed at evaluating the progress of the European Union in fulfilling its educational goals as set out in the Europe 2020 strategy and further developed in the 2030 Agenda for Sustainable Development (SDG 4).

The quantitative analysis applied in this paper combines descriptive and inferential statistical techniques in order to comprehensively assess the progress and convergence of EU member states in achieving the educational objectives set by the Europe 2020 strategy and SDG 4 of the 2030 Agenda.

The descriptive statistical analysis allows to evaluate the current state and variability of the two main indicators:

- early leavers from education and training (ELER) and
- tertiary education attainment rate (TEAR) across EU member countries.

This part of the analysis provides insight into differences in performance, dispersion from the EU average, and deviations from national or EU targets. Such descriptive evaluation directly answers the first research question (**RQ1**), which focuses on **how EU member states have progressed toward the educational goals by 2020**.

The second stage of the quantitative approach applies regression trend analysis, designed to estimate the future trajectory of both indicators up to 2030. By testing alternative functional forms (linear, logarithmic, and polynomial), the analysis identifies the model with the highest explanatory power and statistical significance (based on R^2 and F-tests). This enables an evidence-based prediction of whether the EU as a whole is likely to meet its 2030 targets. Hence, the regression analysis provides an empirical response to the second research question (**RQ2**), which examines **whether the current dynamics of change are sufficient to achieve the targets set for 2030**.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/e6532399867

The quantitative methods were chosen because they allow a transparent, comparable, and replicable assessment of educational performance across countries and over time. In addition, regression-based forecasting supports policy evaluation by indicating the pace and direction of convergence toward the 2030 Agenda goals. Together, these analytical steps ensure that the research findings are statistically sound and directly aligned with the paper's main objectives - evaluating the progress to date and predicting the probability of achieving SDG 4 in the European context.

Descriptive analysis

In the first step, a descriptive analysis is conducted to evaluate the extent to which EU member states fulfilled their national targets by 2020. The relative deviation of each country from its national or European target is expressed as:

$$D_{i,t} = \frac{X_{i,t} - T_i}{T_i} \times 100 \quad (1)$$

where:
$D_{i,t}$ – deviation of country i in year t from the target value,
$X_{i,t}$ – actual value of the indicator,
T_i – target value (national or EU).

This indicator allows for a direct comparison between member states, showing by what percentage they exceed or lag behind their target.

Trend analysis

The second step involves forecasting the future development of the monitored indicators up to 2030 using regression analysis. The general regression function can be expressed as:

$$Y_t = f(t, \beta) + \varepsilon_t \quad (2)$$

where:
Y_t – predicted value of the indicator at time t,
$f(t,\beta)$ – trend function dependent on time and regression coefficients,
ε_t – random error term.

To identify the best-fitting trend, several functional forms are tested:

Linear trend:

$$Y_t = \alpha + \beta t + \varepsilon_t \quad (3)$$

Logarithmic trend:

$$Y_t = \alpha + \beta \ln(t) + \varepsilon_t \quad (4)$$

Polynomial trend of the second degree:

$$Y_t = \alpha + \beta_1 t + \beta_2 t^2 + \varepsilon_t \quad (5)$$

The function with the highest explanatory power and statistical significance will be selected for forecasting values for 2025–2030.

ENTREPRENEURSHIP AND SUSTAINABILITY ISSUES
ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/e6532399867

Model evaluation

To assess model quality and reliability, several statistical measures are used:

Coefficient of determination:

$$R^2 = 1 - \frac{\sum(Y_t - \hat{Y}_t)^2}{\sum(Y_t - \bar{Y})^2} \quad (6)$$

This coefficient expresses how much of the total variability of the indicator is explained by the model.

F-test for overall model significance:

$$F = \frac{SSR/k}{SSE/(n-k-1)} \quad (7)$$

where:
SSR – regression sum of squares,
SSE – residual (error) sum of squares,
k – number of independent variables,
n – number of observations.

Models with statistically significant coefficients (p-value < 0.05) and the highest R^2 are considered the most appropriate for predicting the future development of educational indicators.

4. Results

4.1 Early leaving from education and training

As was already stated, one of the sub-goals of the Europe 2020 strategy in the field of education, which is also one of the sub-goals of SDG 4 of the 2030 Agenda for Sustainable Development, is to address the problem of early leaving from education and training. Given that the Europe 2020 strategy is no longer in effect, it is possible to evaluate the success or failure of member countries in achieving this goal. Figure 1 shows the degree to which a country is lagging behind or exceeding its national target for this particular indicator. Positive values represent the percentage by which the actual achieved value of the monitored indicator exceeds the national target. Conversely, negative values express the percentage by which the country lags behind the target value. By 2020, the European Union managed to meet the target of 10%, even exceeding this target by 0.1 percentage points. Nine countries had a national target set at the level of the EU27 target. Due to the seriousness of the problem related to early leaving from education and training, Bulgaria, Romania, Italy, and Spain set national targets exceeding 10%.

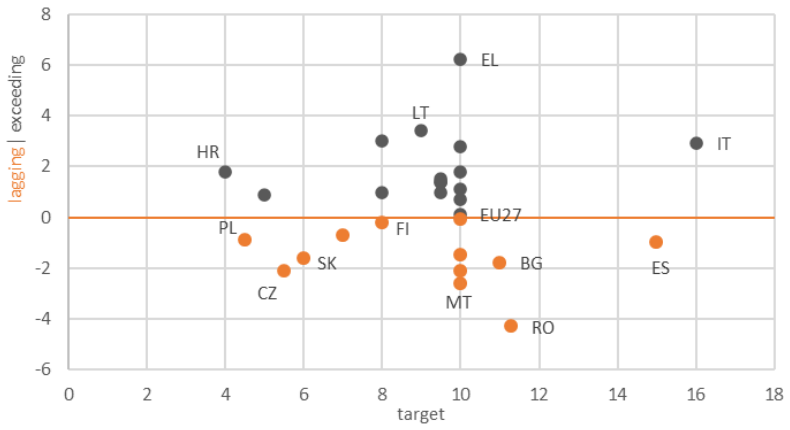


Figure 1. Distance of countries from target values in 2020 for the indicator of early leaving from education and training
Source: own processing based on data from Eurostat, 2025

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/e6532399867

From the 27 EU member countries in 2020, 12 countries lagged behind their national targets. In Romania, the proportion of young people prematurely leaving education or training was 4.3 percentage points behind the target, in Malta it was 2.6 percentage points, and in the Czech Republic and Hungary it was 2.1 percentage points each. Countries that also failed to achieve the set goal by 2020 include Bulgaria, Slovakia, Cyprus, Spain (lagging between 1 and 1.8 percentage points), Poland, Sweden, Finland, and Germany (lagging between 0.1 and 0.9 percentage points). On the contrary, 15 member countries managed to fulfill the set goals.

Regarding the progress achieved, the leader among the member countries in the monitored indicator is Greece, which exceeded its national target by as much as 62 percentage points. This positive result can be explained to some extent by an ambitious national target of 10%. Croatia, as the second in a row, achieved an early leaving from education and training rate of 2.2%, which is the best result within the EU. With this, it met its national target, which was 4%, and exceeded it by 45 percentage points. Denmark, whose national target was at the level of 10%, only exceeded it by 7 percentage points.

Overall, however, significant disparities can be seen among the member countries in the indicator of early leaving from education and training. This is a result of the different policies applied, as well as the tools and specific measures enforced in EU countries. For this reason, the 2030 Agenda continues to deal with this issue, according to which the proportion of people who prematurely leave education and training should be less than 9% by 2030 (the target for the EU27). This indicator is also used to express the principles of the European Pillar of Social Rights and to monitor the goals of sustainable development.

Given the fact that not all countries have their own target values set for the period up to 2030, the following analysis will focus on a comparison with the average target for the EU27, i.e., 9%.

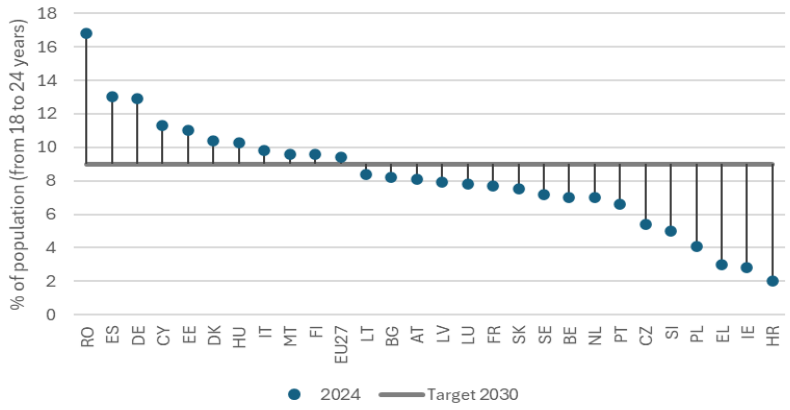


Figure 2. Distance of countries from the 2030 target for the indicator of early leaving from education and training
Source: own processing based on data from Eurostat, 2025

Based on data from Eurostat, it can be stated that in 2024, 17 countries were below the EU's target value (Figure 2), which means that in these countries less than 9% of young people aged 18-24 prematurely left education and training in the monitored year. The average value for the EU27 in 2024 was 9.4%, which points to the necessity of reducing the share by at least 0.4 percentage points by 2030. The country farthest from the target was Romania with an indicator value of 16.8%. This was followed by Spain (13.0%) and Germany (12.9%).

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/e6532399867

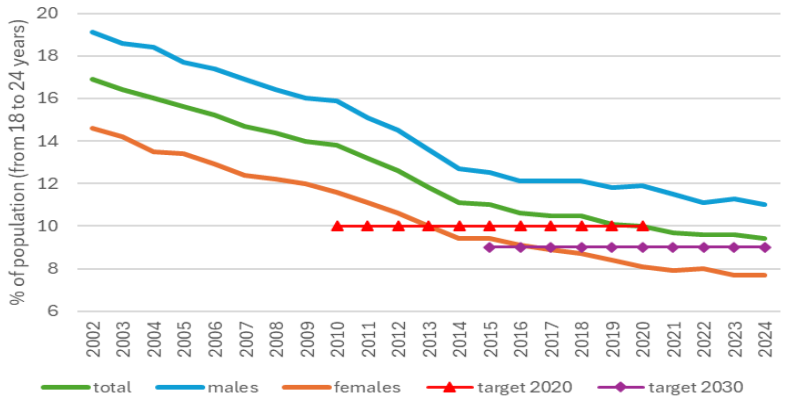


Figure 3. Development of early leaving from education and training in the EU by gender and convergence towards the targets
Source: own processing based on data from Eurostat, 2025

From a long-term perspective, the share of the population aged 18 to 24 who prematurely leave education and training out of the total population in this age category is developing positively, i.e., it is decreasing. While this indicator was at the level of 16.9% in 2002, in 2024 it was 9.4%, which means a slight lag behind the target value (Figure 3). Throughout the entire monitored period, women performed better than men in terms of gender and have been reaching the target value since 2017. In 2024, men in the EU significantly lagged behind the target.

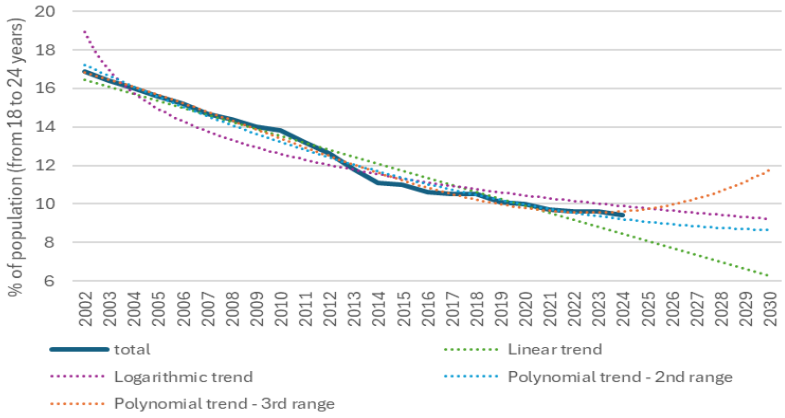


Figure 4. Expected development of the indicator early leaving education and training in the EU by 2030
Source: own processing

The current development of the monitored indicator can be expressed through several functions (Figure 4). The results of the testing show that the most probable trend of development is described by a 2nd-degree polynomial function. The p-value for the intercept is 3.47E-27<0.05, and for the regression coefficients, it is 2.33E-12<0.05 and 6.84E-06<0.05, which indicates the statistical significance of both the intercept and the regression coefficients (Table 1). The result of the F-test, 1.49E-19<0.05, confirms the statistical significance of the entire chosen model.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/e6532399867

Table 1. Results of regression analysis

Regression Statistics	
Multiple R	0,993426
R Square	0,986895
Adjusted R Square	0,985584
Standard Error	0,301982
Observations	23

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	137,35	68,67	753,06	1,49E-19
Residual	20	1,82	0,09		
Total	22	139,17			

	Coefficients	*Stand. Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	17,80	0,21	86,15	3,47E-27	17,37	18,23
X Variable1	-0,60	0,04	-15,03	2,33E-12	-0,68	-0,51
X Variable2	0,01	0,00	6,03	6,84E-06	0,01	0,01

Source: IBM SPSS

If the development of the indicator representing the share of the population aged 18-24 who prematurely left education and training were to follow a linear function (Table 2), the EU27 would achieve the 2030 Agenda goal this year. The value of the indicator would fall below the required 9%. The other extreme case is if the past development were to follow a 3rd-degree polynomial function. In that case, the EU would show a year-on-year increasing trend in the monitored indicator, moving it further away from the set target for 2030.

Table 2. Expected development of the early leaving from education and training indicator until 2030

	2025	***2026***	***2027***	***2028***	***2029***	***2030***	***Target***
$y = -0{,}3639x + 16{,}832$ $R^2 = 0{,}9631$	8,10	7,73	7,37	7,01	6,64	**6,28**	**9**
$y = 0{,}0097x^2 - 0{,}596x + 17{,}799$ $R^2 = 0{,}9869$	9,08	8,96	8,86	8,78	8,72	**8,67**	**9**
$y = 0{,}0009x^3 - 0{,}0217x^2 - 0{,}2882x + 17{,}119$ $R^2 = 0{,}9934$	10,14	10,41	10,78	11,23	11,79	**12,46**	**9**
$y = -2{,}888\ln(x) + 18{,}945$ $R^2 = 0{,}9004$	9,77	9,65	9,54	9,43	9,32	**9,22**	**9**

Source: self-calculations

The results of the regression analysis, however, showed that the most accurate model can be considered the one expressed by a 2nd-degree polynomial function, i.e., quadratic. According to this development, the EU27 would gradually improve in the monitored area and would succeed in reducing the share of people prematurely leaving education and training below 9% for the first time in 2026.

4.2 Tertiary education attainment

The second sub-goal in the field of education is achieving tertiary education. This is based on the indicator representing the share of the population with a university education aged 30-34 in the total population of that age group. The target value of this indicator, which was to be achieved under the Europe 2020 strategy on average for the EU27, was 40% and under the 2030 Agenda it is 45%.

Figure 5 allows us to assess the values of the share of individuals aged 30-34 with tertiary education in relation to the set national targets. The perspective of fulfilling the national targets of the Europe 2020 strategy offers a different view of the successes of individual member countries. The largest overshoot in the indicator relative to the set national target among member countries was achieved by Latvia, which exceeded its national target

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/e6532399867

by almost 45 percentage points. Greece, the Netherlands, Cyprus, and Denmark also achieved excellent results. In total, 17 member countries met their national targets in 2020.

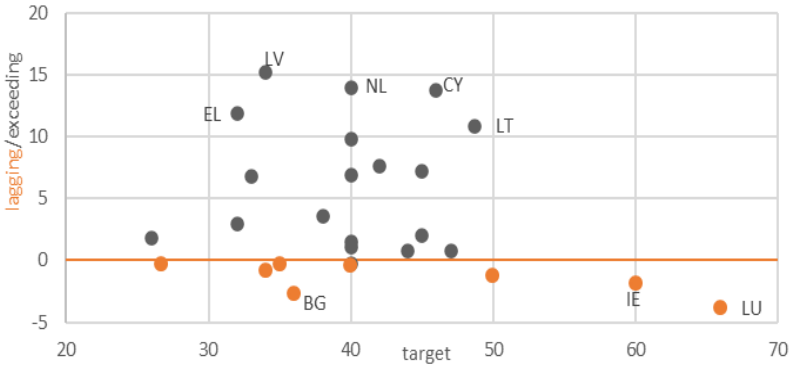


Figure 5. Distance of countries from target values in 2020 for the indicator of individuals with tertiary education completed aged 30-34 in 2020
Source: own processing based on data from Eurostat, 2025

An interesting fact about this indicator is that Luxembourg had the highest share of people aged 30-34 in 2020 (62.2%). However, given its highest target of 66%, it did not meet its goal. Similarly, Ireland and France set ambitious targets that they failed to meet. The result for Germany is also interesting, as it lagged the most behind its national target among the member countries, by almost 13 percentage points. The second most lagging country behind its national target was Bulgaria.

Successfully completed tertiary education is becoming increasingly important given the increased demand for highly skilled individuals in the EU labor market. Tertiary education plays a fundamental role in society by fostering innovation, boosting economic development and growth, and generally improving the well-being of citizens. In February 2021, the Council of the European Union (Rada Európskej únie, 2021) approved a resolution on a strategic framework for European cooperation in education and training towards the European Education Area and beyond (2021-2030). This resolution sets a Union-wide target for the share of people aged 25-34 with tertiary education to be at least 45% by 2030. It is therefore necessary to point out the change in the age category for the 2030 target. This change will disrupt the continuity of data, as well as the possibilities for comparing the fulfillment of goals when tracking the continuity of the Europe 2020 strategy and the 2030 Agenda.

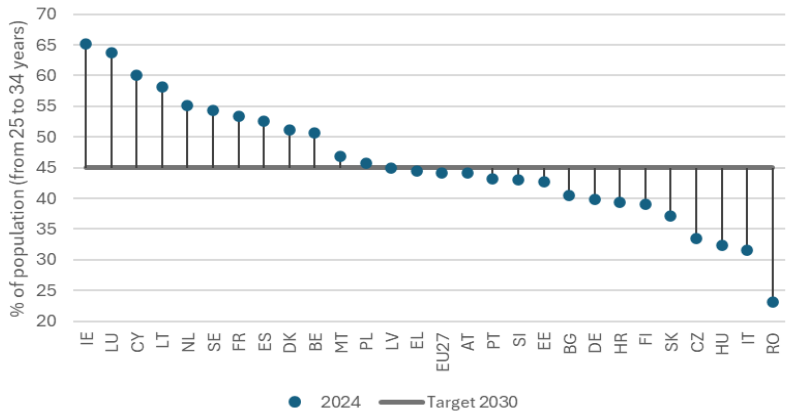


Figure 6. Distance of countries from the 2030 target for the indicator of tertiary education attainment
Source: own processing based on data from Eurostat, 2025

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
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A comparison of the 2030 targets and the shares of people aged 25-34 with tertiary education is presented in Figure 6. We recorded a value of over 45% for the indicator in 12 countries. The leaders are Ireland, Luxembourg, and Cyprus, with shares higher than 60%. The average value in the EU is 0.9 percentage points below the set target.

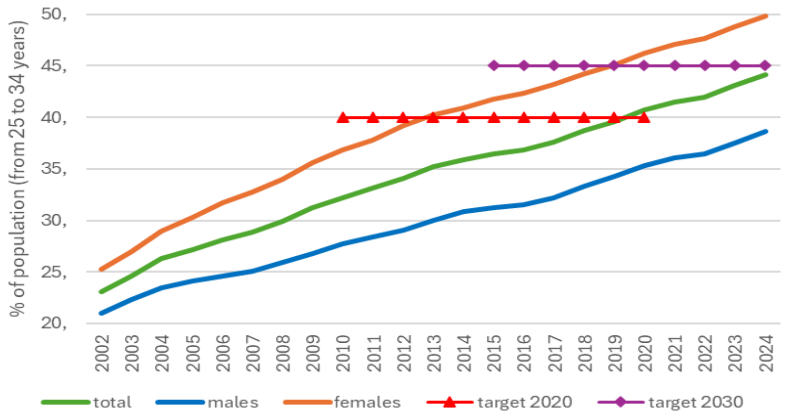


Figure 7. Development of tertiary education attainment in the EU by gender and convergence towards targets
Source: own processing based on data from Eurostat, 2025

Four countries, in particular, contribute negatively to the evaluation of the indicator, where the share of people aged 25-34 with tertiary education lags behind the European average by more than 10 percentage points (in the case of Romania, it is even 21.8 percentage points).

From a long-term perspective, the share of the population aged 25-34 with tertiary education out of the total population of this age group is also developing positively for the EU average, i.e., it is increasing. While in 2002 this indicator was at 23.1%, in 2024 it was 44.1%, which means a slight lag behind the target value (Figure 7). Also in this indicator, women achieve better results than men, exceeding the target value since 2019. They were similarly successful in achieving the 40% target related to the Europe 2020 strategy.

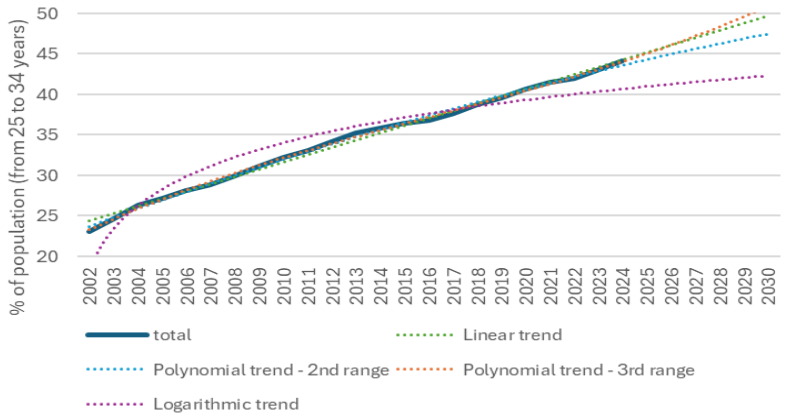


Figure 8. Expected development of the indicator tertiary education attainment in the EU by 2030
Source: own processing

The past development of the indicator can be expressed through several functions and trends shown in Figure 8. The results of the testing show that the most probable trend of development is described by a 2nd-degree polynomial function. The p-value for the intercept is 4.71E-28<0.05, and for the regression coefficients, it is 1.84E-16<0.05 and 7.21E-05<0.05, which indicates the statistical significance of both the intercept and the regression coefficients (Table 3). The result of the F-test, 3.93E-26<0.05, confirms the statistical significance of the entire chosen model.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
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Table 3. Results of regression analysis

Regression Statistics	
Multiple R	0,998559
R Square	0,99712
Adjusted R Square	0,996832
Standard Error	0,346712
Observations	23

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	832,27	416,13	3461,76	3,93E-26
Residual	20	2,40	0,12		
Total	22	834,67			

	Coefficients	*Stand. Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	22,58	0,24	95,21	4,71E-28	22,09	23,08
X Variable1	1,12	0,04	24,71	1,84E-16	1,03	1,22
X Variable2	-0,01	0,00	-4,98	7,21E-05	-0,01	-0,01

Source: IBM SPSS

If the development of the indicator representing the share of the population aged 25-34 who have completed tertiary education were to follow a linear function (Table 4), the EU27 would achieve the 2030 Agenda goal this year. The value of the indicator would rise above the required 45% and to almost 50% by 2030. Also in this case, the development described by a 3rd-degree polynomial function can be considered the least realistic due to relatively sharp year-on-year changes.

Table 4. Expected development of the tertiary education attainment indicator until 2030

	2025	***2026***	***2027***	***2028***	***2029***	***2030***	***Target***
$y = 0{,}9052x + 23{,}502$ $R^2 = 0{,}9935$	45,23	46,13	47,04	47,94	48,85	**49,75**	**45**
$y = -0{,}0092x^2 + 1{,}1254x + 22{,}585$ $R^2 = 0{,}9971$	44,30	44,97	45,63	46,26	46,88	**47,48**	**45**
$y = 0{,}001x^3 - 0{,}0439x^2 + 1{,}4658x + 21{,}833$ $R^2 = 0{,}9984$	45,55	46,67	47,84	49,09	50,41	**51,81**	**45**
$y = 7{,}0807\ln(x) + 18{,}478$ $R^2 = 0{,}9026$	40,98	41,27	41,55	41,82	42,07	**42,32**	**45**

Source: self-calculations

The results of the regression analysis show that the most accurate model can be considered the one expressed by a 2nd-degree polynomial function. With a probability of 99.71%, the EU 27 should succeed in achieving the required level of tertiary education for 45% of the population in the given age category in 2027.

Discussion

Regarding the tertiary education goal, Dragomirescu-Gaina, Elia and Weber (2015) highlighted an increasing performance gap among states and underscored the constrained opportunity for authentic economic convergence. Cotoi et al. (2011) indicated the necessity of creating and promoting entrepreneurial skills through the educational process. Panitsidou, Griva and Chostelidou (2012) pointed out the need to support lifelong learning through European Union policies. Lifelong learning has also proven to be a significant factor in achieving employment goals in the labor market. Klikocka (2019), Panitsides (2014), and Cuestas et al. (2021) focused on the importance of education for the knowledge economy.

Educational performance has long been considered a crucial element in multidimensional assessments of development and inequality across countries (Ferrara & Nisticò, 2013; Mitrovic et al., 2017; Monte & Schoier,

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2022). Composite indicators have therefore become a valuable methodological approach for capturing the complexity of education systems, enabling both international comparison and policy benchmarking. Numerous studies (Jovanovic-Gavrilovic & Radivojević, 2017; Villar, 2017; Stumbrienė, Camanho & Jakaitienė, 2020; Dominguez et al., 2022) have used such indicators to evaluate national education systems and identify key drivers of performance. In particular, Stumbrienė, Camanho, and Jakaitienė (2020) developed a flexible composite indicator designed to summarize education performance and benchmark countries according to efficiency and inclusiveness. Their findings demonstrated that applying frontier-based methods can shift the analytical focus from mere performance evaluation toward continuous improvement and management of educational outcomes. Other authors, such as Murias et al. (2008), El Gibari et al. (2018), Benito & Romera (2011), Gnaldi & Ranalli (2016), Docampo & Cram (2017), and Bas & Carot (2022), further confirmed the usefulness of composite indicators in assessing the quality and effectiveness of higher education institutions.

The study by Stumbrienė Camanho, and Jakaitienė (2020) concluded that European countries are not bound by a common political approach to establish inclusion and equity within their educational frameworks. They further argued that the economic idea of efficiency must be interpreted differently when used for education, necessitating a focus on the particularities of each country's education system.

The consequences of not fulfilling the SDG 4 goals in achieving tertiary education and reducing the number of early leavers from education and training by 2030 are fundamental, especially for socioeconomic development and equality. Failure to meet these goals can deepen existing inequalities, hinder economic growth, and perpetuate cycles of poverty, especially in low-income countries where education systems are already fragile. The main consequences of this failure are economic, social, and global in nature.

The economic consequences can be considered to reduce competitiveness of the workforce. Insufficient achievement of tertiary education limits the qualification profile of the workforce, which reduces overall productivity and the potential for economic growth (Heleta & Bagus, 2021). The problem is also the increase in early leavers from education, leading to a less educated workforce. This has a negative impact on innovation activity and the overall performance of the economy (Cuestas et al., 2021).

The social consequences can include, for example, the deepening of inequalities. Failure to meet the SDG 4 goals can widen social disparities, especially for marginalized groups who already face barriers to accessing education (Vindigni, 2024). Another problem is the dependence on foreign aid, as countries may increasingly rely on external assistance, which weakens local educational capacity and sustainability (Heleta & Bagus, 2021). Deficiencies in education can also have an impact on global development, as education is a catalyst for achieving other sustainable development goals. Therefore, a failure to meet SDG 4 can hinder progress across the entire development agenda (Brissett, 2023). On the other hand, some argue that an excessive focus on SDG 4 might overlook the need for immediate, context-specific interventions that respond to local educational challenges. This can lead to ineffective policies that do not reflect the unique needs of different populations.

Conclusions

The aim of the article was to evaluate and analyze the progress in fulfilling the educational targets within the European Union, as defined by the Europe 2020 strategy and further developed in the 2030 Agenda for Sustainable Development (SDG 4), and to project the possible future development of the monitored indicators up to 2030. Using descriptive and regression trend analysis, we were able to obtain specific findings in two key areas, reflected by research questions RQ1 and RQ2.

1. Achievement of national targets by 2020 (RQ1)

The analysis of the indicator for the share of individuals leaving education and training early showed that the EU as a whole met its main target (below 10%). However, only 15 out of 27 member states successfully achieved their individual national targets. The countries that lagged behind, despite progress, primarily included Romania, Spain, and Germany. The greatest progress was recorded by Greece, Croatia, and Ireland.

In the area of tertiary education attainment, progress was more significant. 17 out of 27 member states met their national targets. This indicates a more successful trajectory for the EU towards SDG 4.3. Greece, the Netherlands, Cyprus, and Denmark achieved excellent results. The most significant shortfall against the national target was shown by Luxembourg, Bulgaria, and Ireland.

2. Projection of target fulfillment by 2030 (RQ2)

The regression trend analysis demonstrated that if the current dynamics of change persist, the EU as a whole is highly likely to meet the target for the share of early leavers from education and training (below 9%) by 2030. Specifically, the best estimated polynomial trend of the 2nd order predicts that the target value could be achieved as early as 2026.

In the area of tertiary education as well, the analysis suggests that the EU is on track to meet the target (at least 45%). This could be achieved as early as 2027 if the projected development follows a 2nd order polynomial function.

The novelty of our research lies in the methodological linking of two key EU strategies and the application of quantitative predictive models. Unlike predominantly retrospective descriptive studies, our work systematically tested several functional forms (linear, logarithmic, polynomial) to estimate future development, thereby providing a more realistic and robust estimate of the trajectory of SDG 4 goal achievement. Such a detailed comparison of regional disparities based on the estimated trend for individual targets up to 2030 represents a unique contribution to the discussion on sustainable development in Europe.

The results obtained have significant practical value for policymakers at both the European and national levels. Data on lagging countries clearly point to areas where increased financial and methodological support from the European Social Fund should be directed. Overall, our analysis provides a quantitative basis for the review and optimization of national educational strategies to ensure alignment between the global commitments of the 2030 Agenda and European regional goals.

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TOWARDS MORE SUSTAINABLE CONSUMPTION VIA QUALITY MANAGEMENT OF GLASSWARE WASHING

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Abstract. Over the past twenty years, the number of households equipped with automatic dishwashers has increased more than fifteenfold in Poland. Numerous studies indicate that mechanical washing, in addition to several advantages, most often results in faster deterioration of dishes compared to manual washing. An experiment was developed to subject decorated glassware to repeated mechanical washing with various chemicals to determine the nature of the effect of the substances on the surface of the decoration. It was necessary to develop a new objective test method, as the current methods are highly subjective. The results of the experiment show that the cleaning agent used significantly affects the degree of material loss in a statistically significant way. These differences are evident both when considering the time of appearance of the first loss and the rate at which the losses increase. It can be stated that the regular use of the same agent for a prolonged period will have a significant impact on the durability of the decoration, and therefore, on the service life of decorated glass. This is important because in today's sustainable world, it's critical not to make purchases of things that aren't needed. Consumers who know the relationship between glassware decoration and dishwasher detergents will be more aware and informed, which may result in better purchases.

Keywords: mechanical washing; resistance of decorations; glass; paint; detergents; sustainable consumption; circular economy

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1. Introduction and review of literature

Over the past twenty years, the number of households equipped with automatic dishwashers has increased more than fifteenfold in Poland. Currently, this type of equipment is found in more than 50% of all households (Alejandre et al., 2024). These devices are designed to speed up and simplify the process of cleaning dishes, which, with the current pace of life and numerous work obligations, is a great convenience for many people. Therefore, it can be assumed that the popularity of this type of equipment will continue to grow in the future. Automatic dishwashing brings many advantages, the most important of which include:

- saving time devoted to household chores (Dubis et al., 2024);
- automatic dishwashing leaves significantly less bacteria on the products than handwashing. The study conducted at the University of Louisville shows that the average number of bacteria on dishwasher-washed dishes was less than one, while on the same dishes washed by hand the average number of bacteria was 390 per plate (Gambogi et al., 2008);

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- the automatic dishwashing procedure using proper detergents removes certain viruses from the dishes (Schilling-Loeffler et al., 2024);
- saving water and detergents, which translates directly into care for the environment (Stamminger & Bockmühl, 2025);
- energy saving, as many users desire low-energy consumption dishwashers (Tewes et al., 2024a, 2024b);
- reduction of the generated carbon footprint – modern dishwashers are constantly being improved in this regard (Alejandre et al., 2022);
- long lifespan of dishwashers, allowing these appliances to be used for a long time, usually for several years, although some models operate efficiently for up to 20 years (Tecchio et al., 2019).

On the other hand, issues related to sustainable consumption are becoming increasingly important today. Sustainable consumption is inherently connected to the broader concept of sustainable development, which refers to a stable form of progress that integrates resource use, investment activities, technological advancement, and institutional transformation and interdisciplinary approach (Ead et al., 2023).

Such an approach ensures that current developmental processes do not compromise the ability of future generations to fulfill their own needs and aspirations. Sustainable consumption involves the deliberate and efficient use of available resources to support development while minimizing negative environmental impacts and safeguarding the well-being of both present and future generations. A key factor in achieving this goal is the presence of conscious and responsible consumers – typically represented by households – who understand the motivations behind their choices and align their behaviors with the principles of sustainable consumption (Baláková et al., 2024; Srbová & Jaderná, 2024; Atkociuniene et al., 2025). This chapter discusses selected examples of consumer practices and behaviors whose implementation plays a crucial role in advancing sustainable consumption (Cabańska et al., 2024).

From the perspective of environmental protection and resource conservation, it is necessary to build new consumer habits (Gomez-Olmedo et al. 2024). One element of the circular economy concept is managing natural resources so that their circulation in the economy is as long as possible (Muradin, 2024). One solution may be for consumers to adopt a philosophy of minimalism, meaning they should stop using unnecessary products (Agrawal et al., 2025. Nguyen et al., 2025).

However, to assess which products meet the principle of minimalism and are truly essential, research is needed to understand the interrelationships between specific product groups and their environmental impact. Individual user habits are also important. The results of such research can be useful in developing new consumer habits (Blackburn et al., 2025).

Automatic dishwashing reduces detergent and energy consumption (Venkatesh, 2022); however, it can also lead to the faster deterioration of glassware, necessitating more frequent replacement of dishes. Short-term use of the same dishes is therefore inconsistent with sustainable consumption.

Numerous studies have been carried out, indicating that mechanical washing, in addition to several advantages, most often results in faster deterioration of dishes compared to manual washing. Both the material from which the dish is made and the decorations, such as those made with paint, can be destroyed. Manufacturers of kitchen accessories are constantly looking for methods to strengthen their products and make them more and more resistant to dishwasher washing.

Detergents are also used in the mechanical washing process and are primarily responsible for removing dirt. They differ in composition (there are chlorine- or phosphorus-based agents) and form (capsules or liquid agents). Most cleaning products include:

- anionic surfactant compounds (AZPC) – responsible for: surface moisturizing, emulsification and dispersion of contaminants, and deep penetration into the dirt layer. More important groups of anionic surfactant compounds include: alkyl nesulfonates, soaps, sodium, potassium and ammonium salts of alkyl sulphates, salts of esters of sulphosuccinic acid with fatty alcohols, as well as salts of alpha-olefin sulfonates;

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- non-ionic surfactant compounds (NZPC) – may function as: emulsifiers, dispersants or greasing agents. They are also perfect for dirt removal, and when combined with anionic surfactants, they often exhibit a synergistic effect. They can also function as foam stabilizers. The largest share among NZPCs are ethoxylates of: fatty alcohols, esters, and oils;
- sequestrants – are compounds that remove ions (e.g., calcium, magnesium) contained in hard water, among others, by creating complexes. This group of compounds includes: sodium polyphosphate, ethylenediaminetetraacetic acid sodium salt (EDTA), sodium gluconate, and sodium citrate;
- organic solvents – are responsible for supporting the cleaning process. They have properties of dissolving contaminants or accelerating the drying of cleaned surfaces. Depending on composition and usage of a cleaner, the function of solvents may vary. The most commonly used ones include hydrophilic solvents, e.g., ethyl, isopropyl and isobutyl alcohol, glycol ethers and hydrophobic, fat-soluble solvents, i.e. paraffin, fatty acid methyl esters, paraffin oil, and silicone oils;
- abrasives – support the mechanical removal of dirt. They help reduce the cohesiveness of dirt, detach it from a surface and disperse it. The choice of an abrasive and its suitable granulation depends on the type and hardness of the cleaned surface. Initially, sand or ash were used as abrasives in cleaners. Currently, wood flour, chalk, silica, ground quartz, glass powder, and pumice are used. There are also abrasives based on macromolecular compounds such as: granulated polyvinyl chloride (PCV), granulated polythene, and polyurethane powder. Products containing abrasives are produced in the form of powder, polish and liquid suspension;
- viscosity modifiers – lead to a product with viscosity suitable for technical and commercial requirements. Commonly used viscosity modifiers can be divided into the following groups: natural and synthetic polymers, surfactants, and inorganic compounds.

Numerous studies carried out to date indicate that mechanical washing, in addition to several advantages, most often results in faster deterioration of dishes compared to manual washing. Both the material from which the dish is made and the decorations made with paint, for example, can be destroyed. Manufacturers of kitchen accessories are constantly looking for methods to strengthen their products and make them more and more resistant to dishwasher washing (Tewes et al., 2024a; 2024b).

There are also several methods for studying the damage caused by washing. Unfortunately, most of these methods are subjective and rely on organoleptic and visual assessments. They provide qualitative results but do not provide meaningful quantitative results (Dubis et al., 2024).

2. Materials and methods

An experiment was developed to subject decorated glassware to repeated mechanical washing with various chemicals to determine the nature of the effect of the substances on the surface of the decoration. It was necessary to develop a new test method, as the current methods had been developed even before modern detergents appeared on the market (Brückner et al., 2010; Lisowski & Sikora, 2023).

The principle of the developed method is based on determining the percentage loss of mechanically cleaned decorations through computer analysis of graphic files that show the condition of the decoration at different stages of the experiment. This analysis consists of extracting the areas covered with thermoplastic paint in the individual photos and measuring the number of pixels present in each area using graphical image processing software. After successive washing treatments, the area covered with paint decreases, causing the number of pixels in the photograph to decrease.

Assessing the quantitative loss of decoration involves determining the amount of loss on each test object using the sample average value (with an assumed accuracy of 2%) and relating it to the size of the decoration before the washing process. This will allow the calculation of the percentage loss of the tested decoration after each washing stage. The method developed is described in detail in the paper written by Dubis and his team (Dubis et al., 2024).

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2025 Volume 13 Number 2 (December)
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Ingredients of household chemicals can cause damage to surfaces that are being cleaned. This may be a result not only of the percentage amount of each ingredient in the cleaning agent, but may also depend on the type of surface that is being cleaned. Test samples were selected in a way that ensures surface repeatability (glass products coming from the same production batch). It should therefore be assumed that the losses of decoration are caused by differences in the chemical composition of individual cleaning agents.
The following cleaning agents were used:

- cleaning agent labelled "S1" with the following composition:
  - phosphates: over 30%;
  - oxygen based bleaching agents, polycarboxylates, non-ionic surfactants: from 5% to 15% in total;
  - phosphonates: max. 5%;
  - enzymes (protease, amylase);
  - fragrance composition.
- cleaning agent labelled "S2" with the following composition:
  - phosphates: over 30%;
  - oxygen-based bleaching agents, polycarboxylates: from 5% to 15% in total;
  - non-ionic surfactants, phosphonates: max. 5%;
  - enzymes (protease, amylase);
  - fragrance composition.
- cleaning agent labelled "S3" with the following composition:
  - phosphates: over 30%;
  - oxygen-based bleaching agents: from 5% to 15%;
  - polycarboxylates: from 5% to 15%;
  - non-ionic surfactants: max. 5%;
  - phosphonates: max. 5%;
  - enzymes (protease, amylase);
  - fragrance composition.

The use of these cleaning agents is justified by the fact that, in research surveys, they were indicated by customers as being the most frequently used by them. All the cleaning agents used were in tablet form, as tablets are the form most often used by consumers (Tewes et al., 2024a, 2024b).

It is noteworthy that the declared composition of washing preparations by manufacturers is only an approximate composition, in which the ingredients are divided into groups defined as ranges. The effect of this situation is the impossibility of recognizing differences between particular agents based only on their composition stated on the packaging. Consumers, therefore, have no way of differentiating between the properties of a preparation before it is applied.

3. Results and discussion

The results of the measurements included material obtained after taking 12,600 photographs, covering a total of thirty glasses. Photographs were taken five times of each of the seven sections of each glass before the start of washing and after each cycle performed until the paint disappeared entirely on the tested products.
The results were analyzed using descriptive and mathematical statistical methods. The analysis included:

- determining the values of the basic measures: position (arithmetic mean) and dispersion (standard deviation, extreme values);
- determining the functions reflecting the change in the amount of paint remaining on the products resulting from washing (calculated as the percentage loss of pixels), where X – the number of the washing procedure, Y – the number of pixels or the percentage loss of the number of pixels (The analysis was conducted using Statistica 10 package);
- verification of the hypothesis about the normality of the distribution of measurement results – $\chi 2$ compliance test, the result of which determines the test used in the analysis of variance, (Mynarski, 2003; Stanisz, 2006);
- verification of the hypothesis about the variation in the number of pixels (after each subsequent washing procedure) depending on the type of cleaning agent. For this purpose, the method of one-factor analysis of

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/p7678484772

variance (Fisher-Snedecor F test) was used, supplemented by *post-hoc* analysis in the form of the least significant NIR difference test.

Verification of all hypotheses was carried out at the selected significance level $\alpha = 0.05$. The results of pixel count measurements for individual decoration elements are presented in Table 1. In the further analysis, the results after the 7th, 8th, 9th, and 10th washings in solutions S1 and S2, as well as after the 9th and 10th washings in S3, were excluded due to the majority of glasses showing a result of 0.

Table 1. Average measurement results of square elements (number of pixels) for each glass.

Agent	Glass	Number of washing procedures										
		0	1	2	3	4	5	6	7	8	9	10
S1	**1**	3,028	3,045	3,000	1,991	1,509	1,019	164	12	0	0	0
	2	3,375	3,345	2,987	2,210	1,241	627	0	0	0	0	0
	3	3,539	3,668	3,012	2,106	1,252	557	405	42	0	0	0
	4	3,625	3,280	3,024	1,540	1,014	316	59	0	0	0	0
	5	3,480	3,166	2,478	835	559	67	0	0	0	0	0
	6	3,406	2,906	2,482	924	541	42	0	0	0	0	0
	7	3,984	3,336	2,363	962	409	88	0	0	0	0	0
	8	3,351	3,247	2,640	2,029	977	473	36	0	0	0	0
	9	3,421	2,896	2,763	1,044	447	78	0	0	0	0	0
S2	**1**	3,316	3,160	2,798	2,779	2,461	1,699	994	0	0	0	0
	2	3,388	3,050	2,801	2,730	2,115	1,117	261	68	0	0	0
	3	3,461	3,380	2,839	2,546	1,676	212	100	0	0	0	0
	4	3,503	3,235	3,005	2,760	2,002	876	312	245	31	0	0
	5	3,369	3,182	2,876	2,454	1,182	52	0	0	0	0	0
	6	3,599	3,139	3,096	2,961	1,896	883	105	0	0	0	0
	7	3,665	3,414	3,275	2,937	1,679	225	2	0	0	0	0
	8	3,892	3,249	3,246	2,600	2,162	1,141	635	260	0	0	0
	9	3,600	3,485	3,097	2,841	1,845	473	73	0	0	0	0
S3	**1**	4,033	3,836	3,675	3,186	3,138	2,235	1,795	1,483	215	0	0
	2	3,696	3,447	3,264	3,241	3,052	2,844	2,168	1,243	0	0	0
	3	3,757	3,421	3,304	3,292	3,035	2,763	1,787	1,269	83	0	0
	4	3,736	3,251	3,368	3,226	2,989	2,711	2,078	1,307	256	98	0
	5	3,693	3,540	3,420	3,372	3,166	2,724	2,068	1,223	0	0	0
	6	3,552	3,296	3,378	3,392	3,117	2,631	2,319	1,706	416	0	0
	7	3,155	3,114	3,046	2,898	2,330	2,431	1,592	1,152	270	117	71
	8	3,984	3,847	3,535	3,529	3,241	3,254	1,818	1,150	0	0	0
	9	3,300	2,959	2,892	2,968	2,936	2,061	1,899	761	50	0	0

Source: own study

In further analysis, the results of the measurement after the 7th, 8th, 9th and 10th washes with S1 and S2 and after the 9th and 10th washes with S3 were dropped due to the result of 0 for the vast majority of glasses. The results of the pixel count measurements for each decoration section are presented in Table 2.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/p7678484772

Table 2. Average measurement results of each section (number of pixels) for each glass.

Agent	Glass	Number of washing procedures										
		0	1	2	3	4	5	6	7	8	9	10
S1	**1**	99,578	97,053	92,283	60,058	49,660	40,160	12,744	2,878	454	0	0
	2	103,570	103,387	89,457	52,621	40,478	21,741	5,705	1,665	0	0	0
	3	101,161	100,316	84,508	55,222	31,232	13,527	5,349	386	0	0	0
	4	105,820	105,471	89,337	51,713	33,428	13,490	3,379	797	0	0	0
	5	101,494	101,463	73,476	25,566	13,697	3,037	500	0	0	0	0
	6	101,704	94,315	73,397	34,163	20,871	2,486	0	0	0	0	0
	7	109,892	101,178	75,581	30,842	10,112	802	342	160	0	0	0
	8	101,417	101,095	89,060	64,674	47,899	23,466	7,237	255	0	0	0
	9	103,410	98,867	93,697	23,391	8,973	3,797	176	0	0	0	0
	10	97,981	95,437	78,289	41,759	25,824	9,740	633	0	0	0	0
S2	**1**	100,799	99,955	98,754	94,899	87,299	54,898	33,018	13,290	5,160	493	0
	2	98,984	97,361	93,878	79,986	49,172	32,023	8,224	2,532	408	0	0
	3	95,046	94,341	93,487	88,728	73,639	14,094	3,533	1,983	0	0	0
	4	104,495	102,982	98,078	89,907	66,388	31,235	16,551	12,795	1,824	0	0
	5	102,931	101,014	95,558	83,501	33,557	6,411	914	0	0	0	0
	6	101,269	99,232	98,691	96,037	62,088	37,044	11,613	2,469	527	0	0
	7	104,708	101,438	96,574	93,235	46,781	19,862	4,009	2,427	0	0	0
	8	107,425	104,440	100,106	96,321	84,901	36,464	17,409	4,802	749	0	0
	9	104,692	100,306	98,551	89,216	42,098	10,719	2,543	362	0	0	0
	10	100,817	99,288	95,121	85,982	57,964	26,990	10,248	4,437	695	0	0
S3	**1**	108,052	106,181	105,178	104,195	104,525	77,197	62,448	51,268	13,294	2,999	903
	2	113,009	112,542	110,806	108,926	108,688	80,355	71,908	24,193	2,339	0	0
	3	116,186	114,604	113,664	112,304	111,551	89,275	76,061	48,161	3,788	134	0
	4	115,276	113,945	113,104	112,449	111,331	104,647	62,831	41,767	3,393	1,309	0
	5	123,591	123,142	121,987	121,155	120,894	86,596	69,287	43,589	11,377	z0	0
	6	114,026	113,487	113,188	112,905	112,218	87,618	61,063	30,311	4,141	355	0
	7	98,811	98,454	98,197	97,921	97,213	82,990	61,847	41,664	12,780	5,874	1,207
	8	123,657	123,236	122,560	122,560	118,637	104,519	41,280	20,574	744	0	0
	9	108,844	106,778	105,952	103,959	101,912	70,773	66,078	21,464	2,328	0	0
	10	111,446	110,074	109,075	107,125	100,806	77,166	58,240	34,905	6,128	1,112	227

Source: own study

In further analysis, the results of measurement after 8, 9 and 10 washes with S1, after 9 and 10 washes with S2 and after 10 washes with S3 were dropped due to the result of 0 for the vast majority of glasses.

The results of testing the hypothesis of whether the empirical distribution matches the theoretical (normal) distribution, using the χ^2 test, are presented in Table 3.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/p7678484772

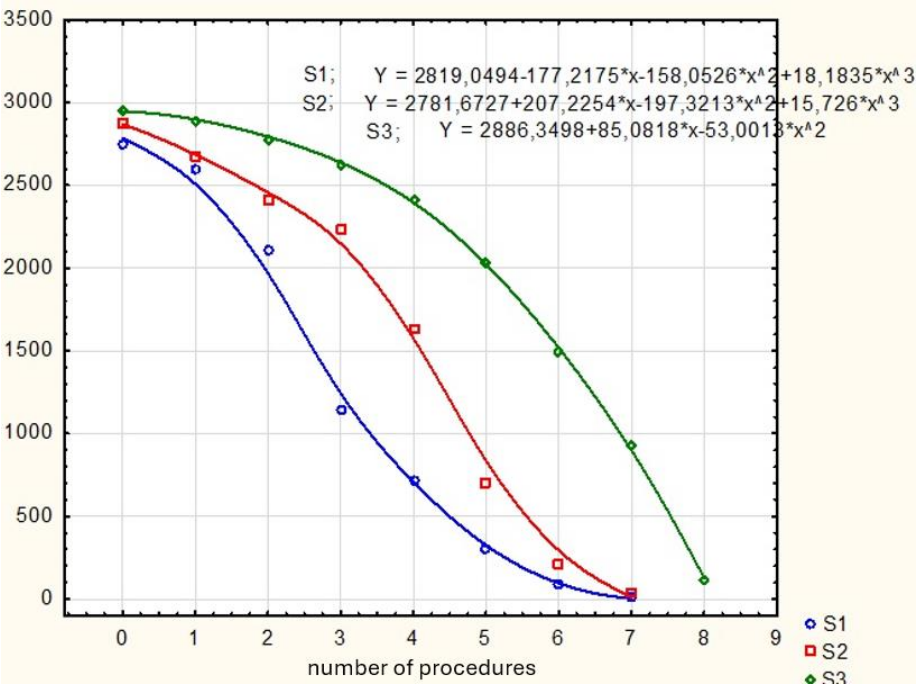
Table 3. Results of verification of the hypothesis of normality of distributions.

	Agent		Number of washing procedures								
			0	1	2	3	4	5	6	7	8
Circle	S1	χ^2	17.99*	11.71*	8.27*	17.52*	18.97*	14.70*	6.65*	-	-
		p	0.207	0.469	0.31	0.225	0.215	0.399	0.355	-	-
	S2	χ^2	0.68*	5.52*	0.27*	2.06*	10.78*	11.72*	12.17*	-	-
		p	0.998	0.992	1	0.999	0.547	0.551	0.501	-	-
	S3	χ^2	0.77*	6.46*	3.78*	4.10*	3.24*	3.71*	5.80*	-	-
		p	0.992	0.989	0.999	0.999	0.999	0.998	0.76	-	-
Square	S1	χ^2	7.94*	16.90*	20.74*	22.09*	16.06*	19.58*	12.04*	-	-
		p	0.54	0.392	0.156	0.106	0.188	0.133	0.099	-	-
	S2	χ^2	0.06*	0.79*	0.92*	1.98*	7.99*	8.06*	13.74*	-	-
		p	1	0.992	0.999	0.999	0.844	0.427	0.132	-	-
	S3	χ^2	0.30*	0.35*	0.08*	0.96*	13.49*	5.48*	1.27*	-	-
		p	0.999	0.999	1	0.987	0.703	0.996	0.999	-	-
Sections	S1	χ^2	8.15*	1.90*	8.61*	5.15*	11.91*	10.11*	**107.15**	**120.04**	-
		p	0.148	0.168	0.126	0.273	0.103	0.124	**0**	**0**	-
	S2	χ^2	0.90*	0.95*	1.93*	8.82*	10.71*	13.34*	**84.85**	**301.3**	-
		p	0.999	0.999	0.999	0.657	0.468	0.305	**0**	**0**	-
	S3	χ^2	1.44*	8.98*	10.09*	14.26*	16.64*	11.56*	**27.78**	18.31*	-
		p	0.999	0.832	0.756	0.355	0.216	0.564	**0.001**	0.369	-

Source: own study

Symbol (*) next to the χ^2 value indicates no significant difference between the empirical and normal distribution at the significance level $\alpha = 0.05$. The χ^2 statistic values show that almost all tested empirical distributions closely resemble the shape of a normal distribution ($p < \alpha$). However, values in bold indicate a significant difference, allowing the hypothesis of normality to be rejected. Therefore, variance analysis (F-test) was performed only for distributions consistent with the normal distribution (circular and square elements – washes 0 to 6, sections – washes 0 to 5).

The average pixel counts for circular elements, square elements, and entire sections after successive washing treatments are shown in Figure 1, Figure 2 and Figure 3.



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2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/p7678484772

Figure 1. Average results of measurements of the number of pixels of circular elements after successive washing treatments with different agents.
Source: own study

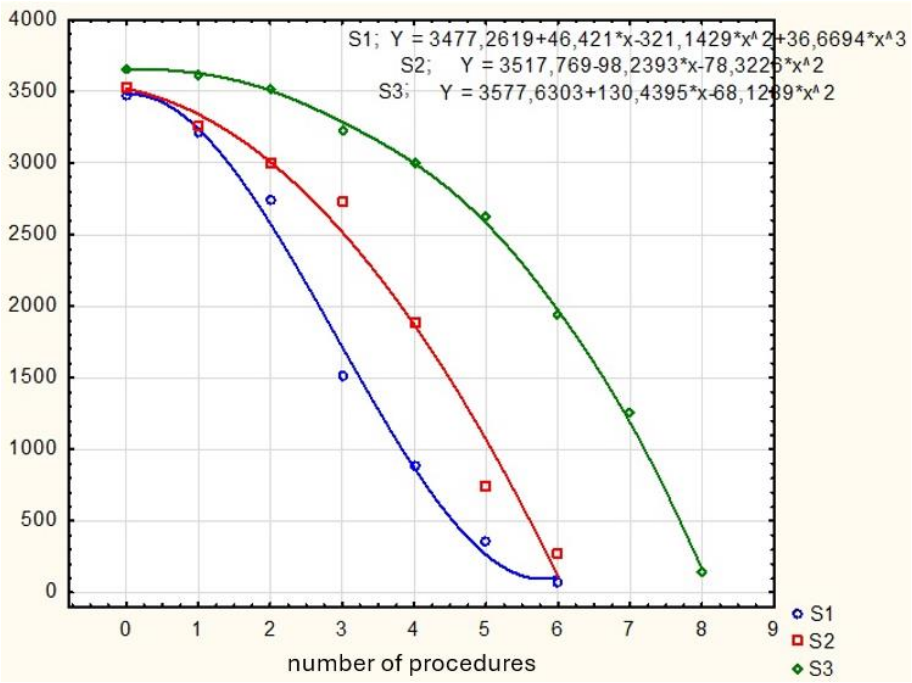


Figure 2. Average results of measurements of the number of pixels of square elements after successive washing treatments with different agents.
Source: own study

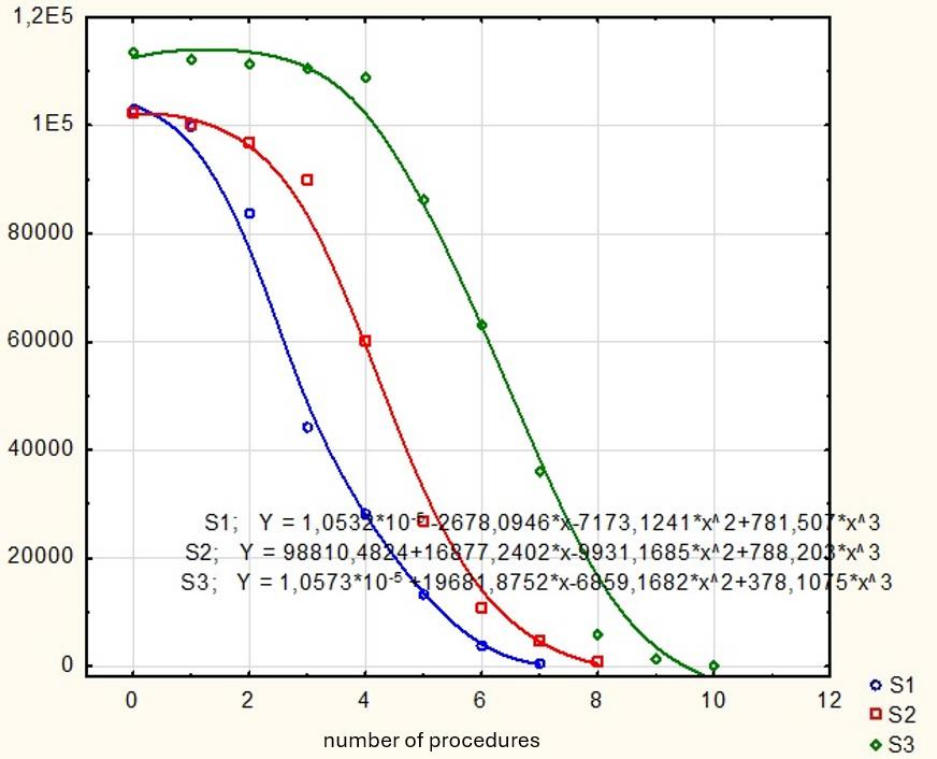


Figure 3. Average results of measurements of the number of pixels in sections after successive washing treatments with different agents. *Source:* own study

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/p7678484772

The measurement results for round elements, square elements, and individual sections (pixel count) of all glasses after successive washing treatments with different agents are presented in Tables 4, 5, and 6.

Table 4. Measurement results of round elements (pixel count) of all glasses after successive washing treatments with different agents (selected statistical measures and results of variance analysis).

Number of washing procedures	Cleaning agent	Statistical measure				Analysis of variance	
		Average	Standard deviation	Minimum	Maximum	F	p
0	S1	2,753.7	206.77	2,426.3	3,127.2	1.86	0.177
	S2	2,871.3	136.03	2,673.8	3,133.6		
	S3	2,954.0	292.63	2,438.4	3,354.8		
1	S1	2,595.9	225.65	2,238	2,987.7	0.86	0.436
	S2	2,667.7	189.41	2,512.9	3,024.6		
	S3	2,883.7	290.85	2,336.1	3,206.6		
2	S1	2,108.0 a	124.83	1,922.5	2,278.1	24.32*	0
	S2	2,408.5 b	152.98	2,171.3	2,658.1		
	S3	2,768.8 c	220.12	2,303.7	2,947.4		
3	S1	a 1,140.8	339.23	725.1	1,562.0	76.99*	0
	S2	b 2,232.7	210.93	1,821.4	2,480.1		
	S3	c 2,624.4	218.53	2,318.3	2,946.7		
4	S1	a 712.6	344.80	231.4	1,093.2	70.06*	0
	S2	b 1,633.9	311.92	1,286.6	2,285.8		
	S3	c 2,413.3	251.27	1,975.2	2,795.2		
5	S1	a 304.5	267.11	0.0	670.1	79.07*	0
	S2	b 698.0	320.75	109.0	1,239.1		
	S3	c 2,038.8	328.78	1,595.4	2,736.0		
6	S1	a 94.6	117.67	0.0	341.1	139.27*	0
	S2	b 209.7	265.60	0.0	753.1		
	S3	c 1,497.3	182.18	1,189.1	1,827.9		

Source: own study

The symbol (*) next to the F-value indicates that the hypothesis of no differences should be rejected ($\alpha = 0.05$). Identical letter symbols next to mean values indicate no statistically significant differences between them ($\alpha = 0.05$). The calculated F-values justify rejecting the null hypothesis after the 2nd, 3rd, 4th, 5th, and 6th washing treatments, thus it can be concluded that the washing agent significantly affects the degree of degradation. Before washing and after the 1st wash, no significant differences were observed. The NIR test showed that after the 2nd, 3rd, 4th, 5th, and 6th washes, agent S1 caused the highest degradation, while S3 – the lowest

Table 5. Measurement results of square elements (pixel count) of all glasses after successive washing treatments with different agents (selected statistical measures and results of variance analysis).

Number of washing procedures	Cleaning agent	Statistical measure				Analysis of variance	
		Average	Standard deviation	Minimum	Maximum	F	p
0	S1	3,467.7	254.48	3,027.7	3,983.8	1.38	0.271
	S2	3,532.5	179.03	3,315.7	3,891.8		
	S3	3,656.0	286.74	3,154.7	4,032.5		
1	S1	3,210.0	242.42	2,896.4	3,668.0	1.80	0.187
	S2	3,254.9	143.29	3,050.0	3,485.3		
	S3	3,612.3	299.81	2,959.2	3,846.8		
2	S1	a 2,749.9	266.94	2,363.4	3,024.4	13.61*	0
	S2	b 3,003.8	185.87	2,798.0	3,275.3		
	S3	b 3,520.3	236.94	2,892.3	3,674.7		
3	S1	a 1,515.6	576.91	835.1	2,209.8	52.38*	0
	S2	b 2,734.2	172.81	2,454.2	2,961.1		
	S3	c 3,233.9	200.12	2,898.4	3,529.3		

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/p7678484772

4	S1	a 883.1	406.17	408.6	1,508.9	82.09*	0
	S2	b 1,890.8	363.37	1,181.8	2,460.6		
	S3	c 3,000.4	268.16	2,330.1	3,241.0		
5	S1	a 362.8	335.20	41.7	1,018.5	75.04*	0
	S2	b 742.0	542.00	52.1	1,698.8		
	S3	c 2,628.1	351.50	2,060.7	3,254.3		
6	S1	a 73.8	135.36	0.0	404.9	156.73*	0
	S2	a 275.8	334.93	0.0	993.5		
	S3	b 1,947.1	227.22	1,591.6	2,319.1		

Source: own study

The symbol (*) next to the F-value indicates that the hypothesis of no differences should be rejected (α = 0.05). Identical letter symbols next to mean values indicate no statistically significant differences between them (α = 0.05).

The calculated F-values justify rejecting the null hypothesis after the 2nd, 3rd, 4th, 5th, and 6th washing treatments, thus it can be concluded that the washing agent significantly affects the degree of degradation. Before washing and after the 1st wash, no significant differences were observed. The NIR test showed that:

- after the 2nd wash, agent S1 caused greater degradation than S2 and S3,
- after the 3rd, 4th, and 5th washes, agent S1 caused the highest degradation, while S3 – the lowest,
- after the 6th wash, agent S3 caused less degradation than the other two agents.

Table 6. Measurement results of sections (pixel count) of all glasses after successive washing treatments with different agents (selected statistical measures and variance analysis)

Number of washing procedures	Cleaning agent	Statistical measure				Analysis of variance	
		Average	Standard deviation	Minimum	Maximum	F	p
0	S1	a 102,602.7	4,736.38	92,599.6	118,256.2	68.48*	0
	S2	a 102,116.4	5,018.64	91,534.8	113,289.0		
	S3	b 113,289.7	8,641.84	90,651.8	130,449.0		
1	S1	a 99,858.2	6,029.12	75,319.2	112,014.6	78.48*	0
	S2	a 100,035.7	4,598.38	89,385.2	112,235.8		
	S3	b 112,244.2	8,827.55	90,459.8	128,240.8		
2	S1	a 83,908.4	13,497.91	32,663.0	105,830.8	143.39*	0
	S2	b 96,879.9	4,185.32	89,003.2	109,542.0		
	S3	c 111,371.1	8,758.84	89,733.2	128,728.4		
3	S1	a 44,000.8	20,314.61	735.0	93,011.2	427.13*	0
	S2	b 89,781.1	8,678.28	51,144.2	100,584.0		
	S3	c 110,349.6	8,895.15	90,424.6	125,302.8		
4	S1	a 28,217.2	18,881.01	0.0	72,631.6	344.27*	0
	S2	b 60,388.7	23,738.23	11,729.8	104,561.8		
	S3	c 108,777.4	9,114.68	90,329.2	125,465.8		
5	S1	a 13,224.5	15,816.73	0.0	60,745.8	365.53*	0
	S2	b 26,973.9	20,133.52	0.0	91,961.4		
	S3	c 86,113.5	14,358.35	56,507.0	121,456.6		

Source: own study

The * symbol next to the F value means that the hypothesis about the lack of differences should be rejected (α = 0.05). Identical letter symbols next to the mean values indicate the lack of significant difference between them (α = 0.05). The calculated F-test values justify the rejection of the null hypothesis after all six washing treatments, which means that the washing agent significantly affects the degree of material loss. The NIR test showed that:

- in each of the tested points, agent S3 caused the lowest degradation (compared to agents S1 and S2);
- after washes 2, 3, 4 and 5 agent S1 caused more degradation than agent S2.

The percentage losses of round elements, square elements and entire sections after consecutive washing procedures are shown in Figure 4, Figure 5 and Figure 6.

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2025 Volume 13 Number 2 (December)
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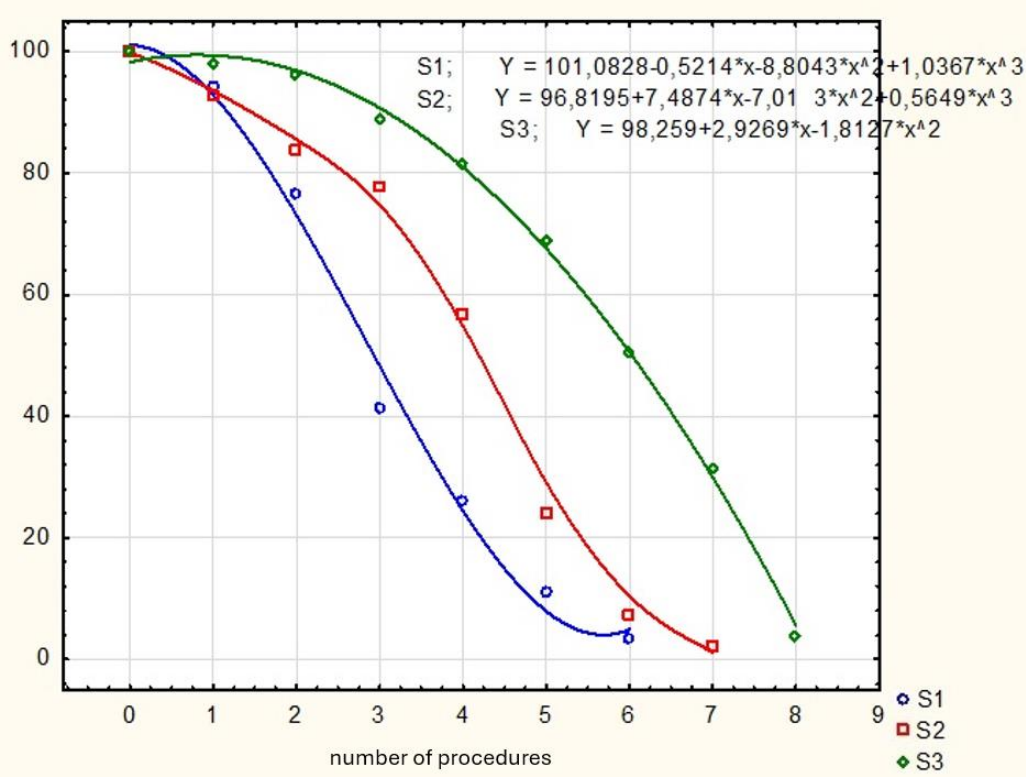


Figure 4. Percentage loss of round elements after consecutive washing treatments with different agents.
Source: own study

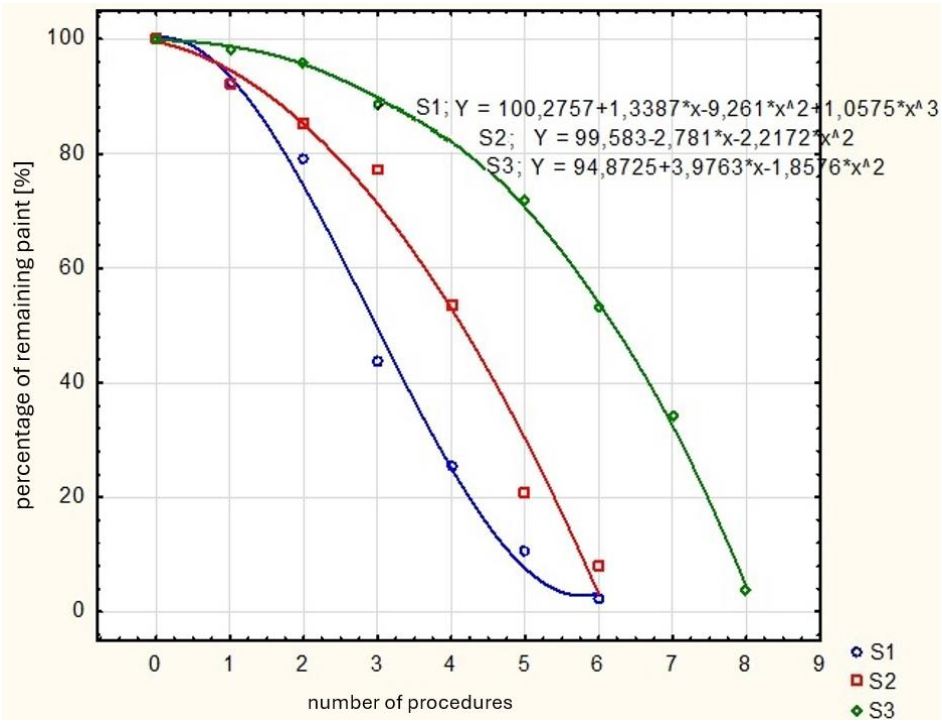


Figure 5. Percentage loss of square elements after consecutive washing treatments with different agents.
Source: own study

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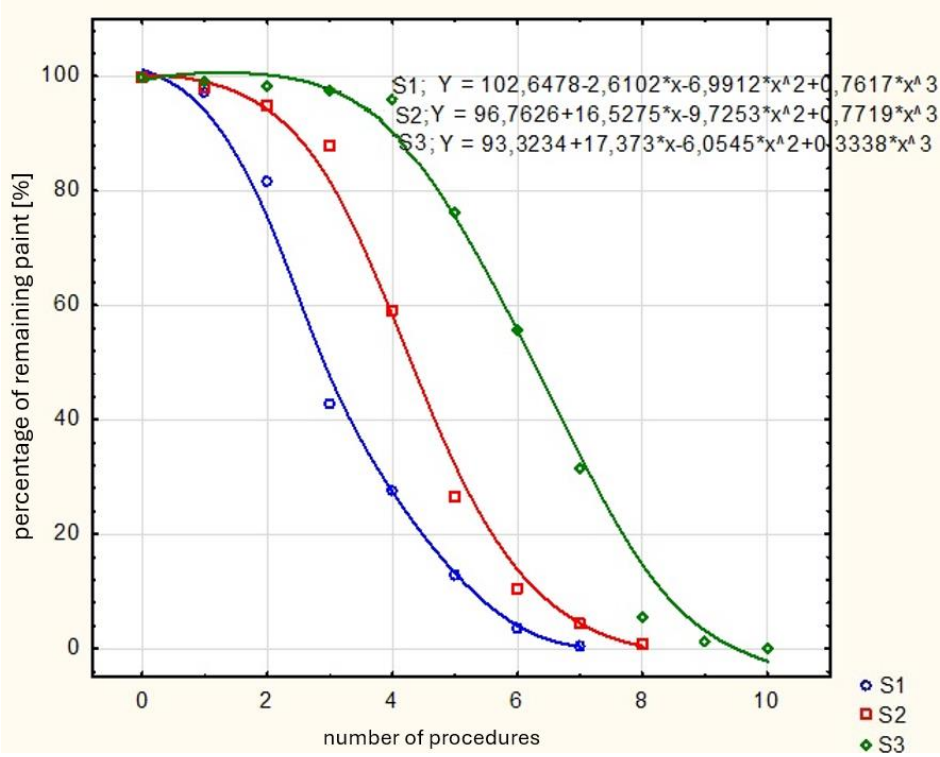


Figure 5. Percentage loss in sections after consecutive washing treatments with different agents.
Source: own study

The results of the experiment show that the cleaning agent used significantly affects the degree of material loss in a statistically significant way. These differences are evident both when considering the time of appearance of the first loss and the rate at which the losses increase.

Conclusions

It can be stated that the regular use of the same agent for a prolonged period will have a significant impact on the durability of the decoration, and therefore, on the service life of decorated glass.
Studies clearly showed that the cleaning agent labelled S3 was the least aggressive toward decorations applied to the glass because:

- the number of washing cycles required to cause the first losses in the decorations is up to four times greater when using this agent compared to the other agents,
- the rate of deterioration of the decorations applied to the glass is up to 50% lower with this agent compared to the other agents.

All three cleaning products used in the study, according to the ingredients listed on their packaging, contain components belonging to the following groups:

- phosphates,
- enzymes that break down proteins and complex sugars,
- compounds based on active oxygen,
- pH regulators,
- solvents,
- foaming agents,
- and fragrances.

Other studies have shown that cleaning agents containing chlorine compounds have a more destructive effect than those based on phosphorus. All agents used in this study were phosphorus-based. However, it is evident that even among them, there are significant differences in the extent of damage they cause to decorations.

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Determining the cause of the damage to the surface of glass coated with paint should therefore be considered on several levels:
Does the product contain chlorine-based compounds?
Has the composition of individual ingredients been selected in such a way as to enhance the action of the household chemical product (synergism) in order to achieve the final cleaning effect? The removal of dirt, and thus the synergistic effect, leads to increased activity of the active components and, consequently, to changes in the surface structure of the glass.
Have solid substances (so-called abrasives) been added?
Since none of the products used in the study contain active chlorine compounds, it can be concluded that the following factors may have had a decisive influence on the changes in the glass surface, depending on the cleaning agent used:

- The product labelled S1 contains the most diverse group of surfactants (non-ionic, cationic and anionic surfactants), which most likely contributes to the synergistic effect,
- The product labelled S1 contains a variety of abrasive ingredients such as kaolin, titanium dioxide and carbonates – mineral substances in solid form.

At the same time, it is worth noting that the conducted analysis aimed to compare the effects of the cleaning agents on decorated glass. No comparisons were made under other conditions or with dishes made of materials other than decorated glass. The most "aggressive" agent for decorated glass may show the best performance on heavily soiled metal or porcelain vessels. Such studies, however, were not the subject of interest in this paper. The conducted research cannot provide a basis for an overall evaluation of the cleaning agents, as these agents were tested solely from the perspective of a single quality factor.

The conducted research, however, provides the basis for formulating a general conclusion that the best durability results of the decoration can be achieved by cleaning the glass with appropriately mild cleaning agents.

Other researchers conducted a study to investigate the effectiveness of various cleaning agents and dishwasher programs. They showed that different detergents available for sale to the general consumers show very different effectiveness in removing soiling. The same is true of different dishwasher programs. They also concluded that the chemicals used can work in conflict with the program used for washing. This is because it may turn out that the user uses a very mild program, but at the same time a very aggressive agent. This can, on the one hand, produce a good cleaning effect, but on the other hand, damage the glassware (Tewes et al. 2024a, 2024b).

In contrast, the present study shows that detergents, which are designed to clean glassware, can also cause damage to the decorations on that glass. Different detergents exhibit significant differences in their ability to remove and destroy decorations.

According to research, water hardness affects the effectiveness of cleaning products. This effectiveness generally decreases with increasing water hardness. Therefore, it may be worthwhile in future studies to investigate the effect of water hardness on the rate of deterioration of decorations on glass.
It is also worth analyzing whether the greater effectiveness of the cleaning agent translates into greater effectiveness in destroying the decoration.

The construction of consumer behaviour models that reflect the actual trends in consumption patterns should be based on taking into account how consumers perceive the relationships between their own individual goals, preferences, motives and modes of action and the use of natural resources (Rumianowska, 2013). Findings reveal that green product attributes and environmental awareness significantly influence purchase intention (Pramesti & Nuvriasari, 2025). Another study confirmed the significant positive impact of green self-identity, environmental lifestyle, environmental knowledge on sustainable purchasing behavior (Ashwini et al., 2025). In practical terms, focusing on people's commitment to environmental protection could thus be a promising avenue for directly promoting sustainable lifestyles (Henn et al., 2025). The study conducted by Alt et al. (2023) highlights the need for marketers and policymakers to design effective green marketing strategies and promote

sustainable consumer practices. The global economy's growing reliance on non-renewable resources, coupled with their progressive depletion, the accelerating impacts of climate change, and the persistent generation of vast quantities of waste, poses significant challenges to the sustainability of future socio-economic development. In response, circular business models have emerged as a promising framework, offering strategies to extend product lifecycles through practices such as repair, refurbishment, the recovery of raw materials from by-products, recycling of end-of-life goods, and initiatives promoting collaborative consumption and product sharing. The proposed solutions must consider various consumer motivations, including the desire to save money, environmental concerns, and the ethical aspects of product selection (Cabańska et al., 2024).

Ultimately, this research underscores the significance of aligning environmental values with consumer identity to foster lasting behavioral change toward sustainability. It is therefore crucial to examine the interrelationships between products and their impact on the natural environment, and then, based on the findings, build new consumer habits. Studies such as those in this paper provide useful results that can help marketers promote appropriate consumer attitudes and, consequently, create valuable social change.

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CUSTOMER PERCEPTION OF AI-SUPPORTED COMMUNICATION IN INSURANCE: A RAPID REVIEW*

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Abstract. Digitalization in the insurance industry has significantly accelerated in recent years, accompanied by a growing use of artificial intelligence in the automation of customer communication. Insurance are increasingly giving more attention to chatbots as an innovative solution to transform the customer service experience, redefining how they interact with users and optimizing their support ptocess. The aim of this study is to synthesize the findings of existing peer-reviewed research on the impact of artificial intelligence technologies supporting customer communication on the customer experience in the insurance industry.Another objective is to explore the prerequisites for adopting an insurance solution, chatbot, and to present current trends in research and future research possibilities. The synthesis of findings is conducted using the Rapid Review methodology, following its established procedures and recommended tools. The relevant bibliographic overview was obtained through a review of studies indexed in the scientific databases WoS and Scopus, as well as sources of grey literature. The process of selecting relevant studies is mapped according to the PRISMA guidelines. The studies that passed the screening process based on predefined inclusion and exclusion criteria were subjected to detailed examination. For the purpose of knowledge synthesis, the following aspects were specified: theme of studies, data collection method, data analysis method, respondents and sample size, applied model, and examined factors. The study shows that current topics focus primarily on identifying positive and negative factors that influence customer feelings when communicating with a chatbot. The data obtained from the surveys were analyzed using the Partial Least Squares-Structural Equation Modeling method. The positive factors supporting the acceptance and intention to use chatbot technology include Trust, Perceived Usefulness, Perceived Ease of Use, Performance Expectancy, and Personalization. Among the negative factors identified were Privacy Concerns, Creepiness, Perceived Risk, and Effort Expectancy. The study has indicated several opportunities for further research.

Keywords: insurance; chatbot; customer perception; artifical intelligence; Rapid Review

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JEL Classifications: G22, O33, D87

1. Introduction

Artificial intelligence (AI) is a machine-based system designed to process input data and, based on that information, generate outputs in the form of predictions, content, recommendations, or decisions. These outputs can subsequently influence either physical or virtual environments. AI systems vary in their level of autonomy and their ability to adapt when implemented in practice (OECD, 2024). These systems simulate features of human intelligence to perform complex tasks, including capabilities such as learning, pattern recognition, decision-making, and language processing (Chilunjika, 2024; Ambrusevič, Gomienė, 2024; Mugunzva, Manchidi, 2024; Mohammed et al., 2025; Mabungela et al., 2025; Mohammed, Ahmad, 2025). The insurance

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industry represents an important pillar of socio-economic stability and individual wellbeing. It currently stands at the forefront of technological innovation and digital transformation. Insurance companies are actively using various digital tools to enhance the quality of their services and improve their competitiveness in the market (Kaur & Singh, 2023). Digital insurance is a modern form of providing insurance services that leverages digital technologies, online platforms, and automated processes to improve customer experience, efficiency, and risk management. The term digital insurance refers to the development, delivery, and management of insurance products and services based on digital technologies (Desikan & Devi, 2021). Digital insurance plays a crucial role in areas such as risk assessment, claims processing, customer communication, and interaction. It encompasses a wide range of solutions, including online policy management, mobile insurance platforms, blockchain-based insurance contracts, and AI-supported risk assessment. By implementing AI within InsurTech solutions, insurance companies gain a competitive advantage, as data form the foundation of the insurance industry. In 2024, the European Insurance and Occupational Pensions Authority (EIOPA) published the results of its EIOPA's 2023 Digitalisation Market Monitoring Survey, conducted among insurance companies across the European Union, which examined the level of AI implementation within the insurance sector (EIOPA, 2024). The increasing use of AI in the insurance industry has necessitated regulation and the establishment of standards. The Artificial Intelligence Act (OECD, 2024) sets out harmonized rules for AI within the European Union and introduces specific provisions governing its use. The main objective is to ensure that AI systems operate in a transparent, fair, and non-discriminatory manner. The aim is to ensure that AI systems operate transparently, fairly, and without discrimination. The regulation prohibits the use of AI systems that manipulate clients decision-making through subliminal or deceptive techniques. It also bans the creation of social scoring systems that evaluate clients based on their behavior or personal characteristics beyond the relevant financial context.

A study conducted by SAS and Coleman Parks Research (SAS, 2024) focusing on the use of GenAI in the insurance industry revealed that as many as 89% of insurers plan to invest in this technology within the next year. According to the study, insurers are primarily investing in GenAI to improve customer satisfaction and retention, reduce operational costs, and enhance risk management efficiency. In 2025, Swiss Re (Swiss Re, 2025) published the results of a survey conducted among insurance customers aimed at assessing their knowledge of AI and GenAI, identifying their level of trust, and examining how it influences their willingness to share data in an era when AI technologies, including virtual assistants and chatbots, are increasingly integrated into the insurance value chain. The survey found that 70% of consumers claim to have at least a basic understanding of how companies use GenAI in chatbots and other applications. Furthermore, 31% of respondents expressed a positive attitude toward sharing personal data in the GenAI era, while 22% reported a negative stance.

To simulate conversations with users, insurance companies use AI-powered chatbot software. The responses can be automated, guiding customers through processes such as sales, reservations, claims reporting, or product returns. Chatbots are capable of learning and adapting to the context and user's needs, facilitating information retrieval without the need for human intervention (de Andrés-Sanchez & Gené-Albesa, 2023a). The use of this technology optimizes communication, enhances customer experience, and helps insurers provide more efficient services (Hunková & Havierniková, 2024; Krulický et al., 2024; Pechová et al., 2024). Chatbots enable customers to complete insurance processes quickly and securely, while also serving as a valuable source of data on customer behavior, preferences, and needs. They can interact with multiple customers simultaneously, offering basic support in resolving inquiries and incidents such as locating a claims adjuster, obtaining information about policy renewal or termination dates, or contacting an insurance broker. The use and advancement of chatbot technology in the insurance industry require a detailed understanding of the level of customer acceptance of these InsurTech solutions. It is crucial to identify the key factors that directly influence trust, perceived usefulness, ease of use, and the degree of personalization, as well as to recognize the main barriers and customer concerns associated with using chatbots in communication with insurers. Research in this field focuses on examining the determinants of AI chatbot adoption, assessing their impact on customer experience and behavior, and comparing their effectiveness with alternative communication methods. Addressing the challenges related to the expansion and acceptance of InsurTech necessitates a thorough literature review. The Rapid Review (RR) method provides not only a comprehensive overview of research trends in the insurance domain but also strategic recommendations for industry practice.

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The aim of this article, in accordance with the Rapid Review (RR) methodology, is to provide an overview of the findings from recently published scientific studies that have evaluated the perception and adoption of chatbot technology by insurance customers worldwide. RR is an approach to reviewing literature characterized by its systematic nature and the use of simplified procedures compared to traditional Systematic Reviews. It enables the provision of evidence within a shorter timeframe (Moons et al., 2021; Smela et al., 2023; Devane et al., 2024). This approach has made it possible to rapidly synthesize and summarize recently published articles and their key findings. A Rapid Review of relevant literature was conducted to answer the following research questions (RQs):

RQ1: What is the scope and structure of the existing published research concerning customer perception of AI-supported communication in the insurance sector?
RQ2: What are the key factors influencing the adoption of digital insurance solutions via chatbots?
RQ3: What are the positive and negative factors that affect customers intention to use and adopt chatbots in their interactions with insurance companies, both now and in the future?
RQ4: What are the future research directions in areas related to the adoption of insurance solutions via chatbots?

The first chapter of the article provides a concise literature review of the examined topic. The second chapter describes the research procedure. The main findings are systematically presented in the PRISMA diagram, followed by a discussion summarizing the most significant results of the Rapid Review. The discussion section addresses the research questions, while the final chapter presents recommendations for future research and practical applications.

2. Literature review

Chatbots and other AI-enabled digital tools are increasingly becoming an indispensable component of the insurance industry (Fichter & Anguelov, 2024). Their deployment reflects insurers strategic efforts to enhance operational efficiency, improve service quality, and enrich the overall customer experience. Chatbots, in particular, hold significant transformative potential to reshape customer service in the insurance sector by enabling faster, more personalized, and data-driven interactions (Atanasious et al., 2024). According to Agarwal et al. (2022), the digital capabilities of insurance companies are expanding significantly through the implementation of artificial intelligence, machine learning, and intelligent devices. Their applications include intelligent claims processing, prediction and detection of insurance fraud (Rawat et al., 2021), personalization of customer experience (Kelley et al., 2018), integration of large language models (LLMs) into insurance operations (Jangjarat et al., 2023), the use of smart contracts and blockchain-based intelligent insurance policies, and AI-powered chatbots (Sosa & Montes, 2022). According to Guanawardane (2023), chatbots enable companies to create a positive customer experience by responding instantly to inquiries, providing consistent information, and efficiently integrating multiple communication channels. While traditional customer support channels are limited by working hours and the capacity of human agents, chatbots can simultaneously handle a large volume of requests (Pabalkar et al., 2025). In this way, they contribute to improving customer satisfaction, strengthening trust in the insurer, reducing operational costs, and increasing customer loyalty. Digital text-based communication is gradually replacing traditional face-to-face interaction as the primary mode of both personal and professional contact (Ellili et al., 2023). The use of artificial intelligence appears to be an effective tool for enhancing customer interactions (Yau et al., 2021). Chatbots enable companies to be proactive and personalized in their communication with customers by providing immediate and consistent responses to their inquiries (Jenneboer et al., 2022). They are integrated across various communication channels, including social media, corporate websites, mobile applications, and digital platforms. Chatbots can instantly respond to customer requests, deliver consistent and accurate information, and collect and analyze customer data. Advanced chatbots can be programmed and customized to deliver more personalized, interactive, and engaging conversations. However, their effectiveness depends on the continuous improvement of underlying technologies to reflect the evolving needs and expectations of customers (Radu & Alexandru, 2022). The digital customer experience holds particular importance in the insurance industry, as customer interactions are relatively infrequent. Due to this limited contact, it is crucial for insurers to provide accurate and relevant information, ensure fast and efficient claims processing, and create a positive customer experience from the very first interaction. This capability is essential for building customer trust and loyalty (Zhang et al., 2021; Amelia et al., 2021).

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2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/z6524286266

However, some empirical studies (Dekkal et al., 2023; Gené-Albesa & de Andrés-Sanchéz, 2025) suggest that the success of chatbot implementation remains mixed. Insurance companies continue to struggle with low levels of customer acceptance of these technologies. Possible reasons include insufficient understanding of customer needs, a lack of communication personalization, concerns regarding data privacy, and a generally low level of trust in artificial intelligence. The growing importance of chatbots and AI in the insurance sector presents a new research challenge. It is likely essential to gain a deeper understanding of the factors influencing customers' acceptance of chatbots. Key determinants include perceived usefulness, ease and convenience of use, trust in the service provider's system, perceived data security and protection, as well as customers' personal experience and digital literacy (Rajaobelina et al., 2021; Janssen, 2022; Cardona et al., 2022). The current state of research indicates that, although insurers are actively investing in chatbots and other digital tools, the level of their adoption by customers has not yet been sufficiently explored. The adoption of chatbots depends on a combination of technological, behavioral, and psychological factors (Cardona et al., 2022; Janssen, 2022). Research in this area draws on established models of user technology acceptance. The Technology Acceptance Model (TAM) emphasizes perceived usefulness and perceived ease of use as the primary factors determining users' attitudes toward a technology and their intention to use it. The Unified Theory of Acceptance and Use of Technology (UTAUT) extends the TAM framework by incorporating additional factors such as hedonic motivation, social influence, habit, perceived service value, trust, and willingness to share personal data. In the context of the insurance industry, the extended UTAUT2 model is commonly applied. According to the TAM (Davis, 1993) and UTAUT2 (Venkatesh et al., 2012) models, perceived usefulness is one of the strongest predictors of new technology adoption. In the insurance industry, customers expect chatbots to simplify communication, accelerate processes, and provide accurate information. When a chatbot meets these expectations, the likelihood of its continued use increases. Users are more willing to adopt chatbots when they are intuitive, user-friendly, and require minimal effort during interaction. In contrast, complex interfaces or ambiguous responses tend to cause customer frustration and reduce their willingness to engage with AI tools. Trust is a key factor in the adoption of chatbots within the insurance industry (Zarifis & Cheng, 2022). Customers entrust insurers with personal data, financial information, and sensitive documents; therefore, they expect secure and transparent data processing. A low level of trust is one of the main reasons for rejecting AI-based solutions, particularly in the financial services sector (Rajaobelina et al., 2021; Chang, 2022; Ivančík, Andrassy, 2023). Modern customers expect chatbots to adapt content to their needs, provide personalized recommendations, and recall previous interactions. According to Jenneboer et al. (2022), personalized communication enhances customer satisfaction, fosters loyalty, and contributes to a more favorable perception of the insurer's brand. The use of chatbots in the insurance sector may raise customer concerns regarding data privacy. Increased sensitivity to data processing leads users to expect clear information from insurers about what data are collected, how they are used, and the measures taken to protect them. The UTAUT2 model highlights the importance of hedonic motivation, the positive experience associated with using a technology. Chatbots that are interactive, friendly, and employ natural language enhance user satisfaction and encourage long-term engagement (Kronemann et al., 2023).

The rapid development of InsurTech solutions in the insurance sector has driven the emergence of several innovative companies specializing in the development of AI-powered chatbots designed to enhance customer communication and service efficiency. Companies are increasingly using AI to read and extract unstructured data from documents and to automatically identify relevant information, perform risk analyses for insurance providers, and transform acquired data into predictive models that support informed decision-making. The developed solutions contribute to enhancing the digital customer experience and optimizing interaction processes (Chisel AI, InsurTech Praedicat, Mantra Labs).

3. Research objective and methodology

Conducting a comprehensive systematic review of chatbot acceptance typically requires several months or even years, which is not ideal for tracking a rapidly evolving topic such as artificial intelligence. Therefore, a Rapid Review (RR) approach was applied in the present study. The request to conduct the presented bibliographic review originated from industry experts. In collaboration with practitioners, a Rapid Review Protocol document was developed, discussed, and approved. Feedback was also provided by members of the academic community. The RR Protocol offers a structured framework for conducting a rapid review, describing an evidence synthesis

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/z6524286266

process that is faster than a traditional systematic review while maintaining methodological rigor (Moons et al., 2021; Pizard et al., 2025; Pena et al., 2025). The key elements of the RR protocol include clearly formulated research questions, a defined search strategy, established inclusion and exclusion criteria, and a structured plan for data extraction and synthesis of findings.

The selection of relevant documents followed the PRISMA methodology (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) (Page et al., 2021). The final search was conducted on September 15, 2025. For data extraction, the scientific research databases Web of Science (WoS) and Scopus were used. To identify relevant articles within these bibliographic databases, a search string was constructed by combining key terms aligned with the study objectives and Boolean operators. The initial search was conducted using the search string presented in Table 1. Through the advanced search function within the title, abstract, and keyword fields of the selected databases, two groups of keywords were combined in various configurations. The first group included terms related to the domains of artificial intelligence (AI), chatbot, voicebot, and voice assistant. The second group consisted of terms associated with the insurance industry and customer satisfaction. The purpose of employing such a broad range of keywords was to ensure that the literature search was as comprehensive and inclusive as possible.

Table 1. Search string for identifying relevant studies in the WoS and Scopus databases

TITLE-ABS-KEY (chatbot* OR "AI chatbot*" OR "virtual assistant*")
AND
TITLE-ABS-KEY (insurance OR "digital insurance")
AND
TITLE-ABS-KEY (perception OR attitude OR acceptance OR adoption OR "customer experiences“)

Source: own elaboration

A similar search strategy was applied to identify relevant sources of so-called grey literature. The inclusion and exclusion criteria (Table 2) ensured that both the selected academic documents and grey literature sources were relevant to the focus of the rapid review. The exclusion criteria allowed for the filtering out of documents during the screening process that did not meet the defined eligibility parameters or lacked sufficient information for further analysis.

Table 2. Inclusion and Exclusion Criteria

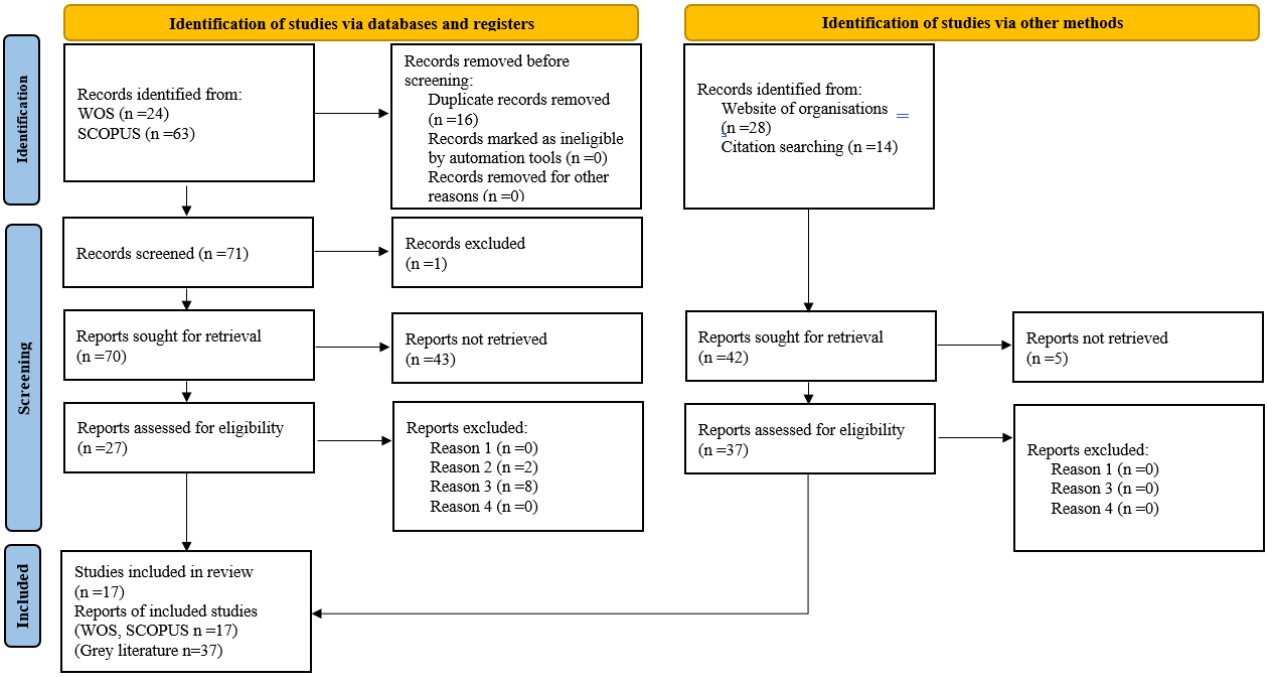
Inclusion Criteria		Exclusion Criteria	
Academic Documents	Companies (grey literature)	Academic Documents	Companies (grey literature)
Papers published between 2022 and 2025	Papers published between 2022 and 2025	Papers outside the specified time period	Papers outside the specified time period
Peer-reviewed journal articles and open-access conference papers	High-quality professional reports	Non-empirical works (conceptual papers, editorials, opinion pieces)	
Documents classified under the research areas: Business Economics, Computer Science, and Social Sciences	Studies related to insurance or customer communication in financial services	Documents outside the selected research areas	Studies unrelated to insurance or customer communication in financial services
Papers published in English	Papers published in English or Slovak	Papers not published in English	Papers not published in English or Slovak

Source: own elaboration

Using the search string, a total of 87 potentially relevant documents were identified across two scientific databases: 24 from WoS and 63 from Scopus, along with 42 sources of grey literature. The process of searching for and selecting relevant documents is illustrated in the PRISMA flow diagram (Figure 1). The Zotero system identified and removed 16 duplicate sources. Subsequently, titles and abstracts were analyzed. Access to full texts could not be obtained in 42 cases. In exceptional instances, studies published in 2021 were also accepted, as their content provided valuable information. Only peer-reviewed journal articles and conference papers were then considered. A total of 27 articles remained for further analysis. Eight studies did not belong to the categories of computer science, business, management, economics, or social sciences. Ultimately, 17 studies were included in the systematic full-text review. The reference lists of the included studies provided an additional 14 sources, five of which were inaccessible. Beyond academic publications, grey literature was also identified from various web platforms and company websites.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/z6524286266

Figure 1. PRISMA 2020 flow chart



Source: own elaboration

It should be noted that the search was limited to a specific time period; therefore, studies published after the search date may have been excluded.

4. Results

From each thoroughly reviewed source, the following aspects were identified: theme of studies, data collection method, data analysis method, respond and samle size, applied model, examined factors. A concise overview of the main findings is presented in Table 3 below.

Table 3. Significant findings from the RR

Study	Theme of Studie	Data Collection	Data Analysis	Sample Size	Applied Model	Examined Factors
Poorna, Deepa (2025)	Acceptance of digital insurance among older adults	questionnaire	CSAT, benchmark with ACSI	20 adults (age 66 – 72)	TAM, ISCM, C-SAT	PEOU, PU, C-SAT Respondents' concerns – financial losses, lack of training, privacy, security
de Andrés-Sánchez et al. (2023)	Attitudes, advantages, and disadvantages perceived in the use of chatbots for insurance contracts and claims reporting	questionnaire 11-point Likert scale	PLS-SEM, Qualitative analysis,	N = 63	TAM, Trust-external variable	PU, PEOU, Trust
de Andrés-Sanchez, Gené-Albesa (2024a)	Acceptance of chatbots, identification of factors and necessary conditions	questionnaire 11-point Likert scale	PLS-SEM, NCA,	N=58	UTAT	EE, SI, Trust, PE, Professional status
Pizzi et al. (2023)	Understanding the psychological mechanisms of trust and acceptance of chatbots.	Experimental design	ANOVA, Factor analysis	N=421	Modified TAM/UTAT	Anthropomorphism, Gaze direction, Self-disclosure,BI, SkepticizmTRUST
de Andrés-Sánchez, Gené-Albesa (2024b)	Acceptance of chatbots by insurance company clients in the management of existing insurance contracts	questionnaire 11-point Likert scale	PLS-SEM	N=226	TAM, Trust-external variable	Trust, PEOU, ATT, PU, BI

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/z6524286266

de Andrés-Sánchez, Gené-Albesa (2023a)	Acceptance of chatbots by policyholders in the management of existing insurance contracts	questionnaire 11-point Likert scale	PLS-SEM,	N=226	UTAT	PE, EE, SI, Trust, Insurance Literacy, BI
de Andrés-Sánchez, Gené-Albesa (2023b)	Analysis of policyholders' attitudes and behavioral intentions to use chatbots	questionnaire 11-point Likert scale	PLS-SEM	N=119	TAM	PU, PEOU, SI, Trust, BI
Jyothsna et al. (2024)	Which chatbot features influence users' initial trust, intent to use chatbots, loyalty, and customer engagement	questionnaire	PLS-SEM	N=271	TAM, UTAUT, DIT	PEOU, PE, SI, Trust, UI
Gené-Albesa et al. (2025)	Acceptance of chatbots in insurance, focusing on factors such as expected performance, expected effort, social influence, and trust	questionnaire, 11-point Likert scale	SEM-PLS, DTR, IPMA	N-226	TAM, UTAUT	IU, PE, EE, SI, Trust
Dekkal et al. (2023)	The study examines factors that influence user trust and their intention to use chatbots	auto insurance quote), questionnaire 7-point Likkert scale	SEM	N=95	TA-Technology Anxiety	Practicity, Personalization, Enjoyment, Privacy concern, Creepines
Cardona et al. (2022)	Factors influencing the intention to use insurance chatbots (ICB)	questionnaire	PLS-SEM	N=215	TAM	PU, PEOU, Trust, IU
Patil et al. (2024)	Evaluation of service quality improvement in insurance through AIPHC	questionnaire	PLS-SEM	N=688	AIPHC adoption Intention	Optimism, Innovativeness, Discomfort, Insecurity
Rajaobelina et al. (2021)	Identifying precursors of creepiness when interacting with customer insurance chatbots	insurance chatbot simulation, questionnaire	SEM	N=430	Developed model Loyalty	Privacy concerns, Usability, Technology Anxiety, Need for Human perception,Trust. Loyalty
Bouhia et al. (2022)	The study examines the determinants of privacy concerns when interacting with a customer chatbot.	Questionnaire after interacting with chatbot	CFA	N=430	Developed model Privacy concerns	Creepiness, Perceived risk, Need fo privacy, Familiarity with chatbot
Pirilä et al. (2022)	Analysis of insurance company customer satisfaction and preferences when using chatbots	questionnaire 7-point Likkert scale	Cronbach's α,	N=225	Technical quality, Process quality	various feelings of respondents
Ferreira et al. (2021)	Analysis of the use of chatbots as a strategic tool for improving the responsiveness and efficiency of customer service	questionnaire	Student's t-test	N=119	TAM	PEOU, IU
Mangla et al. (2023)	Generation Z's perceptions and attitudes towards the use of chatbots in insurance	questionnaire	Analysis pf association	N=120	Perception towards AI-based chatbot	Trust, Capability

Source: own research results

Note: Abbreviations used in the table: AIPHC – AI-powered humanoit chatbots, ACSI – American Customer Satisfaction Index, BI-Behavioral Intention, C-SAT- Customer satisfaction, DTR – Decision tree regression, E - engagement, EE - Effort Expectancy, IPMA – Importance Performance Map Analysis, ISCM - Information System Continuance Model, IU - Intention Use, L-Loyalty, NCA - Necessary Conditions Analysis, PE - Performance Expectancy, PU - Perceived Usefulness, PEOU - Perceived Ease of Use, SI - Social Influence

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/z6524286266

The most important factor identified by respondents in their interaction with insurance chatbots was trust. From the reviewed studies, additional factors influencing respondents attitudes toward the adoption of chatbot technology in insurer–customer interactions were extracted. An overview of the frequency of these factors reported in the reviewed publications is presented in the following graph.

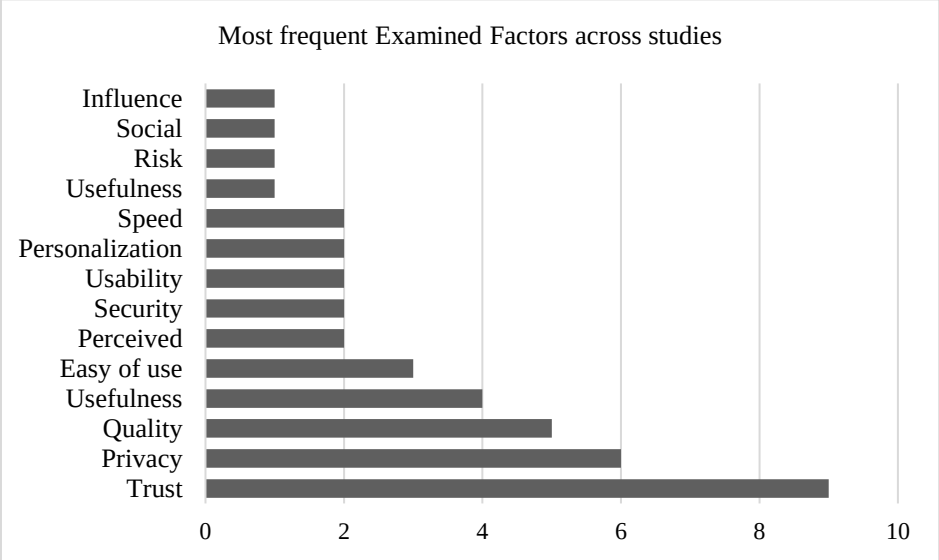


Figure 2. Most frequent Examined Factors
Source: own elaboration

An additional 37 documents were included in the final review, sourced from the websites of companies specializing in the development of chatbots for customer communication in the insurance sector, from the Google Scholar database, and from references cited in the studies reviewed above. The same aspects were identified.: theme of studies, data collection method, data analysis method, respond and sample size, applied model, examined factors. Across all 54 studies, the most common data collection methods were online surveys of insurance customers, questionnaires, and systematic reviews of journal articles. The collected data were analysed using a wide range of quantitative methods, including descriptive analysis, structural equation modelling (SEM), and thematic synthesis. The most frequently applied models were the TAM, UTAUT, and their modified versions. Several models incorporated additional external variables such as trust, personalization, enjoyment, and technological anxiety. Furthermore, new models were developed, including the Unified Efficiency Model, the Satisfaction Model, the Privacy–Trust–Behavioural Model, and other conceptual frameworks. Across most of these studies, the following key factors were identified: usefulness, ease of use, trust, social influence, customer engagement, satisfaction, security, usability, empathy. The sources of grey literature also included documents published on the websites of companies involved in the development and implementation of chatbots in the insurance industry. Most of these companies provide on their websites only the technological specifications of their solutions. They typically offer products in the areas of Voice AI Agent, Chat AI Agent, and AI Agent Assist, as well as their combinations. These solutions are designed for deployment across various sectors, including insurance, banking, healthcare, telecommunications, and government. Among the highlighted and advertised features of these chatbots, the most frequently mentioned technical characteristics and functions include:

1. Training - websites URLs, learning from various file formats, training with predefined question and answer pairs, training using plain text, correction, training using markdown syntax.
2. Features – lead collection, human support fallback, live chat, conversation rating, support multiple chatbot administrators, multilingual AI model selection.
3. Customization – customizing avatar, chat icon, colours, instructions, settings, remove branding, custom domains, knowledge base optimizer.
4. Security – rate limits, restricting domains.
5. Installation – widget, iFrame, share link.
6. Integration – WooCommerce, Shopify, BaseLinker, WordPress, Wix, WebFlow, Custom API integrations.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/z6524286266

The reviewed company websites contained extensive documentation describing the technical features of the offered chatbots; however, studies evaluating the anthropomorphic characteristics of these technologies from the customers' perspective were lacking. No documented studies were found in which companies examined or reported the level of customer acceptance of the technology, nor any that explored the emotions or feelings experienced by customers during interactions with chatbots in the context of insurance-related tasks.

5. Discussion

The aim of the conducted study was to provide an overview of the most recently published research evaluating customers' perceptions of AI-supported communication in the insurance sector, using the Rapid Review methodology. To address the research questions, a total of 54 relevant sources were thoroughly analyzed.

To answer the first research question, the scope and structure of the existing published research were mapped. Most studies were conducted with insurance customers in Europe, while several were carried out in North. All studies examined customers perceptions and emotional responses to conversations with chatbots within specific insurance processes. Spain holds the leading position in terms of the number of published scientific outputs derived from such surveys. The methodology described in the reviewed studies was consistent with standard approaches to publishing survey results. Each study first provided a rationale for the selection of a representative research sample, followed by a detailed description of the data collection procedures. Most studies aimed to validate a specific model explaining customers perception and acceptance of AI technologies in the insurance context. The examined models were often modified by incorporating additional external variables. In the concluding sections, the studies presented key findings and quantified relationships that either supported or did not support the tested hypotheses within the proposed models. The majority of the analyzed publications also included final recommendations for future research and potential practical applications.

The identification of key factors influencing the adoption of digital insurance solutions via chatbots was essential for addressing the second research question. The assessment of the strength of these factors effects was conducted through the application of TAM, UTAUT, or their modified models. In line with the information presented in Figure 1, the most frequently examined domains were trust, privacy, quality, usefulness, and ease of use. Correspondingly, the examined factors within the applied models included Trust, Performance Expectancy, Perceived Ease of Use, Effort Expectancy, Social Influence, and Privacy Concern. All these factors were identified as critical determinants in the adoption of insurance solutions facilitated by AI-supported chatbot technology.

Answering the third research question involved assessing the magnitude and direction of the effects of the examined factors. Across the studies, positive, negative, moderating, and mediating effects were identified. The magnitude of these relationships was quantified using SEM-PLS methods. The study by de Andrés-Sánchez et al. (2023) confirmed that the TAM provides a robust framework for examining chatbot acceptance among insurance professionals. The main determinant was Perceived Usefulness, which had a significant direct effect on Attitude ($\beta=0.697$, $p<0.01$), and was itself strongly influenced by Ease of Use and Trust. Overall attitudes toward chatbots are predominantly negative, with respondents emphasizing technical shortcomings, a lack of empathy, and a perceived reduction in employment opportunities. The overall model explained 69% of the variance. Another study by Gené-Albesa & de Andrés-Sánchez (2025) demonstrated that chatbot acceptance in the insurance sector is a complex phenomenon. The results showed that the most influential variables, in order of importance, were Trust, Effort Expectancy, Social Influence, and Loyalty. Performance Expectancy was found to have no significant effect, which contradicts the traditional TAM and UTAUT models. These findings highlight the need to strengthen trust and user accessibility as essential prerequisites for the broader adoption of chatbots in the insurance industry. In another study by de Andrés-Sánchez & Gené-Albesa (2024a), Effort Expectancy was quantified as the strongest predictor of Intention to Use ($\beta=0.390$, $p<0.01$), followed by Trust ($\beta=0.284$, $p<0.01$). The factor Performance Expectancy was identified as having a negative effect within the evaluated model. Jyothsna et al. (2024) evaluated the impact of various factors on the construct Chatbot Trust and subsequently on Customer Engagement, Chatbot Usage Intention, and Loyalty. The strongest effect was observed for the factor Performance Expectancy ($\beta=0.809$, $p<0.01$), while Compatibility was identified as having a negative influence. The construct Chatbot Trust was then found to have a strong positive effect on

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/z6524286266

Loyalty (β=0.484, p<0.000). Dekkal et al. (2023) identified positive (driver) factors such as Practicality, Enjoyment, and Personalization, and negative (inhibitor) factors including Privacy Concerns and Creepiness. The moderating variable Technology Anxiety was found to reduce the positive effects of Practicality and Personalization on Trust and Intention to Use, while also weakening the relationship between Trust and Adoption among users with lower technological competence. Cardona et al. (2022) reported significant positive effects as follows: Perceived Usefulness → Intention to Use (β=0.550, p<0.001), Trust → Intention to Use (β=0.209, p<0.001), Perceived Ease of Use → Perceived Usefulness (β=0.263, p=0.001), Trust → Perceived Usefulness (β=0.376, p<0.001), and Perceived Ease of Use → Trust (β=0.336, p<0.001). Significant negative effects were observed for Privacy Concerns → Trust (β= –0.401, p<0.001) and Privacy Concerns → Intention to Use (β= –0.020, n.s.). To address RQ3, the following positive factors were generally identified as supporting the acceptance and intention to use chatbot technology: Trust, Perceived Usefulness, Perceived Ease of Use, Performance Expectancy, and Personalization. The effects of these factors were evaluated as statistically significant. The negative factors influencing the intention to use and adopt chatbot technology included Privacy Concerns, Creepiness, Perceived Risk, Effort Expectancy, Compatibility, and Technology Readiness.

The Rapid Review yielded several recommendations that provide an answer to the fourth question. Foremost, insurers should strengthen the determinants of trust, ease of use, and perceived usefulness among customers, while mitigating negative influences. It is advisable to investigate potential moderating factors that may affect the intention to interact with insurance chatbots. Future work should compare results by applying different existing, or newly modified, models to data from the same cross-sectional study. Longitudinal designs are needed to ascertain the long-term effects of antecedents of users' trust and chatbot adoption, with improvements quantified using a proposed metric. Results should be tracked systematically using standardized instruments that are developed and quantitatively validated through reliable models based on modified TAM/UTAUT and newer frameworks. Companies developing the aforementioned technology should verify acceptance through peer-reviewed scientific studies. Finally, findings should also be compared at the local level, taking regional specificities into account.

Conclusions

The objective of the present study was to identify the most recent trends in research on the perception of key positive and negative factors influencing the adoption of AI-supported communication technologies between customers and insurance companies. At present, chatbot technology represents the preferred method of initial customer interaction. However, findings from published studies indicate that several barriers still persist. The dual-perspective approach, combining academic research with industrial implementations, has enabled a more comprehensive mapping of the current state of customer perceptions regarding one of the core AI tools in the insurance sector. The results emphasize the need to strengthen trust and user accessibility as essential prerequisites for the broader adoption of chatbots in the insurance sector. When designing chatbots, it is advisable to apply a moderate degree of anthropomorphism and maintain a neutral appearance, as this approach fosters users' willingness to share personal information and enhances their trust in the technology. The factor of creepiness significantly reduces trust and loyalty in interactions with insurance chatbots and evokes negative emotions. Usability acts as a protective factor, whereas privacy concerns, technostress, and the need for human interaction increase the perception of creepiness. Therefore, it is crucial for insurers to design chatbots that are easy to use, transparent, and privacy-respecting in order to minimize the impact of creepiness on customer loyalty. The strongest predictors of the intention to use a chatbot are trust and perceived usefulness. Privacy concerns and complexity primarily weaken trust rather than directly affecting the intention to use. Technical quality serves as a necessary foundation but is insufficient on its own to build user preference for AI. Process quality—characterized by pleasant, empathetic, and seamless interaction—is crucial for customers to prefer chatbots over human agents. Insurers should therefore combine reliable technical solutions with a high-quality customer experience. The conducted rapid review of customers' perceptions of chatbots in insurance, based on the findings of the analyzed studies, highlighted not only existing research gaps but also practical challenges and successes in implementing AI-supported solutions within the insurance industry.

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MODELLING THE IMPACT OF FINANCIAL SERVICES DIGITALISATION ON ACHIEVING THE GOALS OF SUSTAINABLE ECONOMIC DEVELOPMENT*

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Abstract. The authors have conducted a comprehensive study on the impact of digitalising financial services on achieving sustainable economic development goals in Ukraine, within the context of digital transformation and post-war economic recovery. The purpose of this article is to develop an integrated model that combines logistics and agent-based modelling to assess the potential of digital financial technologies as a catalyst for sustainable economic growth. This approach not only allows for the quantification of the impact of FinTech on key development indicators but also enables the development of public policy scenarios that take into account the nonlinear nature of socio-economic processes and technological adaptation. The economic and mathematical model developed by the authors enables the assessment of the pace, nature, and depth of the introduction of digital financial technologies, as well as their impact on key macroeconomic indicators. The authors propose combining the Gompertz logistic model with agent-based modelling methods, ensuring that both general trends in digital development and the behavioural heterogeneity of financial services users are taken into account. The model was developed based on statistical data for 2018-2024, taking into account key parameters such as the penetration rate of digital banking products, the share of non-cash transactions, the volume of digital lending and investment, and the advancement of digital infrastructure. The model was calibrated, and forecast scenarios were built up to 2028, which makes it possible to identify potential points of acceleration of economic growth through the digitalisation of the financial sector. The results of the study indicate a direct correlation between the level of digitalisation of financial services and the growth of gross domestic product, increased investment activity, productivity growth, and improved public financial management. The proposed model can serve as a tool for strategic planning at the levels of public policy, banking regulation, and financial forecasting.

Keywords: financial services; digitalisation; financial technologies (FinTech); sustainable development; economic stability.

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1. Introduction

In today's rapidly evolving global financial landscape, digital financial technologies (FinTech) play a crucial role in transforming the architecture of economic systems. Not only do they help improve access to financial

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services, increase operational efficiency, and reduce transaction costs, but they also create preconditions for achieving sustainable economic development goals, particularly through financial inclusion, innovative employment, and the development of a green economy. While digitalisation has traditionally been associated with technological progress, it is increasingly seen as a tool for socio-economic transformation, helping to reduce inequality, mobilise investment, and adapt to climate challenges. This issue is especially relevant for economies recovering from systemic shocks, such as the COVID-19 pandemic or military conflicts. In such circumstances, digital financial solutions such as mobile payments, e-wallets, neobanks, P2P lending platforms, and other tools can provide rapid financial inclusion for households and small businesses, while stimulating domestic demand and capitalising on innovation. According to Cibák et al. (2024), under crisis conditions, the financial system requires an integrated approach to risk assessment, which aligns with the concept of developing an integrated model for evaluating the impact of digital financial technologies on sustainable economic development.

However, to effectively realise the potential of FinTechs as a driver of sustainable development, a deep understanding of the mechanisms of their impact on macro- and microeconomic indicators is required. That is why there is a growing need to use mathematical modelling to analyse the relationships between the level of digital inclusion, financial stability, and economic growth dynamics. Logistic models enable the formalisation of the diffusion process of digital innovations in the financial sector, while Agent-Based Modelling (ABM) facilitates the consideration of the heterogeneity of economic agents' behaviour, the impact of regulatory interventions, and social factors influencing technology adoption.

2. Theoretical background

In the context of the modern economy's transformation, the key driver is digitalisation, which encompasses all aspects of society, including the financial sector. The analysis of scientific sources enables us to identify several significant studies that form conceptual approaches to the digital transformation of financial services, reveal the essence of digital financial technologies, and highlight the regulatory, technological, and social aspects of this process.

A significant contribution to the formation of the theoretical and methodological foundations of the digital economy was made by Bilozubenko et al. (2020), who consider digital transformation as a key vector of structural restructuring of economic systems. The authors focus on the transition from traditional models of financial interactions to innovative formats that utilise digital communication channels, mobile services, and remote banking. They also emphasise the need to adapt the legislative and regulatory framework to the new realities of the financial market, which is increasingly operating based on digital algorithms, automated services and intelligent decision-making systems.

The application of intelligent data analysis based on digital technologies, as described by Cherednichenko et al. (2023), confirms the potential of digital solutions to improve the efficiency of financial models in the context of sustainable economic growth. In turn, Kraus et al. (2018) focus on the multicomponent impact of the digital economy, emphasising both technological and social aspects. Their works examine the role of the financial sector in shaping the infrastructure of digital platforms that provide a wide range of financial services in the new environment. A special place is given to the use of distributed ledger technologies, such as blockchain, which, according to the authors, act as a guarantor of transparency, trust, and security in financial transactions. The researchers also consider the relationship between the digitalisation of financial services and increased financial inclusion, but the primary focus is on the cost-effectiveness of new digital models (Androniceanu, 2024a; Androniceanu, 2024b).

Of considerable scientific interest are the works of Balytska and Brovenko (2021), who systematise existing approaches to the interpretation of the category of "digital financial technologies" and provide an in-depth analytical review of its components. The researchers identify four main clusters of scientific analysis: the functioning of financial markets, the development of the digital economy, the behavioural characteristics of users, and technological innovations (Liu et al., 2023; Craciun et al., 2025; Alakoum et al., 2025). The authors' works provide a terminological definition of digital financial services as products of fintech companies,

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including digital payment tools, digital lending, automated asset management, and online insurance, among others. Their approach allows for a deeper understanding of the structure and logic of the digital financial environment as a complex socio-economic system.

Dudynets' (2018) research focuses on the evolution of payment systems in the digital dimension. The author not only studies the mechanism of digital payment services' functioning but also analyses the risks associated with their use in depth. Her work focuses on the aspects of cybersecurity, the protection of personal and financial data, and adapting infrastructure to the challenges of the digital environment. She emphasises the need for a unified regulatory policy to ensure the stability and continuity of digital payment channels. The author's research focuses on innovations in the banking sector, particularly on tools such as mobile banking applications, digital wallets, and platforms based on blockchain technologies. The author considers digital banking services as a response of traditional banking institutions to the challenges of the fintech market. The researcher emphasises the need to develop new approaches to regulating digital services, particularly by updating standards, regulations, customer identification mechanisms, and combating fraudulent schemes. Her work emphasises the importance of building trust between users and financial institutions in the context of digital transformation.

Pochenchuk (2018) pays special attention to the digital transformation of the financial sector, conducting an in-depth analysis of the factors that hinder the effective digitalisation of the financial sector in Ukraine. Her research focuses on the fragmentation of legislative support, the lack of unified standards for digital financial products and services, and the regulatory framework's limited adaptability to innovative business models. The author raises the issue of the low level of digital literacy among the general population, which, in turn, hinders the integration of the latest digital solutions into everyday financial consumption. She proposes a systematic approach to forming a regulatory architecture that supports innovation without compromising the safety and stability of the financial system.

Researchers Demchyshak and Hudyma (2021) examine current trends and challenges in the development of financial technologies in post-crisis economies, particularly in the context of Ukraine. In their works, they emphasise the role of fintech startups as drivers of technological change in the financial sector, capable of offering flexible solutions for a wide range of users. However, the authors also point to numerous infrastructure barriers that hinder this development: underdeveloped digital infrastructure in the regions, poor connectivity between banks and non-bank financial institutions, and limited availability of venture capital funding. As one of the solutions, they propose intensifying the state's role in the digitalisation process through institutional support, tax incentives for innovative companies, and the creation of special regulatory sandboxes for testing fintech products.

Stoiko (2020), in his scientific works, considers the digital transformation of financial services as a tool for overcoming economic challenges and stimulating growth in the real sector of the economy. The author examines examples of the introduction of the latest financial instruments, including digital factoring, smart contracts in bank lending, and automated solutions for small businesses. Attention is also paid to increasing the transparency of financial transactions through digital services, which creates the preconditions for reducing corruption risks and improving access to capital for enterprises.

Significant contributions to the study of the digitalisation of the payment sector were made by Trautman (2013) and Ortina et al. (2023), who thoroughly analysed the risks arising from the rapid introduction of digital payment services. In her works, she identifies the main threats, including cybercrime, the violation of personal and financial data confidentiality, and the incompatibility of national regulatory practices with the rapid pace of technological progress. The author conducts a comparative analysis of international experiences, comparing cybersecurity strategies in the financial sectors of the United States, the EU, and several Asian countries. Her approach is based on the need to implement multi-level security systems that incorporate both technical solutions (such as multi-factor authentication and encryption) and legal mechanisms to protect users' rights.

A comprehensive view of digital security in the financial sector is offered by Trusova and Chkan (2021), who focus on aspects of customer identification, transaction authentication, and the social consequences of the digital divide. In their works, they emphasise that the growing level of automation and algorithmisation of financial

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services gives rise to a new category of risks associated with the loss of control over personal data, access to finance, and increased vulnerability of certain social groups. The authors pay special attention to the technological digital divide, which exacerbates the inequality between users who have access to modern technologies and those who are excluded from the digital financial environment due to objective reasons. They emphasise the need to develop ethical standards and national strategies for digital inclusion in finance (not in the narrow social sense, but in the functional sense of equality of access to financial solutions).

A valuable theoretical and empirical analysis of the structural impact of FinTech on financial markets is presented by Feyen et al. (2021), who demonstrate that digital technologies increase efficiency and competition, but also require the development of new mechanisms to maintain financial stability. Their conclusions are essential for modelling, as they reveal the dual impact of innovation — stimulating inclusion and potentially increasing systemic risks.

The United Nations (2018) paid particular attention to the issue of digital financial inclusion in the context of achieving the Sustainable Development Goals (SDGs), whose policy review identified the digitalisation of financial services as a cross-cutting driver of several SDGs. The report emphasises that the integration of digital instruments into public and private finance strengthens education, healthcare, and social protection systems.

Ushenko et al. (2023), Kum et al. (2024), and Becha (2025) analyse the relationship between digital financial inclusion and economic growth, emphasising that the widespread adoption of digital financial services not only improves access to credit but also stimulates investment activity in sustainable development. The authors highlight the importance of financial literacy among the population and the integration of digital services into government programs, which helps reduce inequality and enhance the efficiency of the economic environment. It should be noted that in the context of further digitalization of the financial sector, it is advisable to use the approach proposed by Iliychovski, Filipova and Petrova (2025) to assess the value of non-public joint-stock companies in conditions of incomplete information to determine the risks of providing financial services.

Marza et al. (2025) proposed the application of AHP and FUZZY AHP methods to assess the level of digital financial inclusion. Their study demonstrated that the combined use of these methods enables modelling the impact of digitalisation on economic development, identifying priority areas for financial investment, and forecasting the effectiveness of sustainable development programs in Central and Eastern European countries. Lee (2024) highlights the regulatory challenges faced by digital banks and alternative lenders. The author demonstrates that the effective implementation of digital financial services depends on the ability of government authorities to adapt regulatory frameworks to new technologies while ensuring security, transparency, and accessibility of financial transactions.

Abbasi and Weigand (2017) systematised the impact of digital financial services on firm performance in their literature review. The authors identify key success factors in fintech integration, including risk management, process standardisation, operational digitalisation, and access to analytical platforms for strategic decision-making.

Faruq and Chowdhury (2025) examine the role of big data in financial markets and its influence on ESG investments. The authors argue that leveraging analytical tools and digital platforms enhances transparency in financial flows, optimises investment decisions, and ensures the sustainability of economic development.

In general, the analysed sources allow us to form a multidimensional view of the digitalisation of the financial sector as a complex and dynamic process that combines innovation, risks, and the need for systemic regulation. Although scientific papers have thoroughly described certain areas of digital change, from payment innovations to institutional support for fintech companies, there is still no unified analytical platform that allows for assessing the impact of digital financial services on macroeconomic indicators and the dynamics of sustainable economic development. It is this gap that determines the relevance of further research aimed at building models for quantitative and qualitative analysis of digital transformations in the financial sector.

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3. Research objective and methodology

The purpose of this article is to build an integrated model that combines logistic and agent-based modelling to assess the potential of digital financial technologies as a catalyst for sustainable economic growth. This approach not only allows for the quantification of the impact of FinTech on key development indicators but also enables the development of public policy scenarios that take into account the nonlinear nature of socio-economic processes and technological adaptation. The study proposes an analytical toolkit for strategic decision-making in the field of digital finance, which can be useful for both government regulators and the private sector.

This study uses an integrated approach that combines logistic modelling and agent-based modelling to analyse the impact of digital financial technologies (FinTech) on sustainable economic development. The primary objective was to develop a model that enables forecasting the dynamics of digital financial inclusion in Ukraine and assessing its impact on economic growth.

To build the model, we utilised official statistics for the period 2018-2024, collected from reliable sources, including the International Monetary Fund's Financial Access Survey, the World Bank's Global Findex database, and reports from the National Bank of Ukraine. The key indicators included the level of digital inclusion, penetration of mobile financial services, availability of digital lending, and infrastructure characteristics, including the number of ATMs per 100,000 population. The model parameters were estimated using the nonlinear least squares method with initial linearisation of the logistic function to simplify the approximation. This enabled the prediction of digital inclusion's medium-term development.

To take into account the individual characteristics of users of digital financial services and complex socio-economic interactions, agent-based modelling was applied. The agent-based model describes the behavior of different groups of agents - consumers, financial institutions, and regulators - that interact in the digital financial ecosystem. Each agent has a set of characteristics, such as the level of digital literacy, financial needs, and risk behaviour, which influence their decision to adopt and use FinTech. The model is implemented on the basis of NetLogo software, which provides flexibility in setting up scenarios and displaying network effects. By integrating macroeconomic trends through logistic modelling and micro-level behavioural characteristics of agents, this methodology allows for in-depth analysis of the digital transformation of the financial sector, forecasting its impact on sustainable economic development, and formulating recommendations for public policy in the field of digital finance.

The general research methods used in this study include system analysis, mathematical modelling, statistical data processing, and computer modelling. The system analysis enabled us to comprehensively consider the digital transformation of the financial sector as a holistic system comprising numerous interconnected elements, including users, financial institutions, regulators, and technology platforms. This approach helped to identify the key factors that determine the pace and quality of digital inclusion.

Mathematical modelling, particularly the use of logistic regression, provides tools to formalise the process of introducing digital financial services, which is typically described by an S-shaped innovation diffusion curve. The method of nonlinear approximation and linearisation of the function allowed us to estimate the main parameters of the model and make forecasts of the development of digital inclusion. Statistical methods were used to process the input data, identify trends, correlations, and perform regression analysis, which ensured the scientific validity of the models built.

Computer modelling, in particular agent-based modelling, was used to simulate the behaviour of different categories of users in the digital financial ecosystem. This approach made it possible to take into account individual differences, dynamic interactions, and network effects that cannot be reflected by traditional methods. The use of modern information technologies for data collection, analysis, and modelling ensured the accuracy, reproducibility, and scalability of the study, which is important for the formation of effective strategies for the development of digital financial services in the context of sustainable economic growth.

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2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/c2899846654

4. Results and discussion

4.1. Results

In today's environment, digital financial technologies (DFTs) are one of the key drivers of sustainable economic growth, as they help to improve the efficiency of financial services, expand access to new instruments, and optimise operational processes in the banking sector. Studying and forecasting the dynamics of DFT adoption is extremely important for formulating an effective public policy that will contribute to the balanced development of Ukraine's economy in the digital era.

Various mathematical models are used to describe the process of spreading digital financial technologies in society. Classical logistic functions based on symmetric S-shaped curves are widely used to model the diffusion of innovations. However, in some cases, the nature of technology adoption is asymmetric, with different growth rates in the early and late stages of adaptation. In this regard, our study chose the Gompertz model, an alternative approach that, due to its asymmetric S-shape, better reflects the real dynamics of digital financial technology adoption.

The Gompertz model allows not only to more accurately describe the growth rate of digital transformation, but also to take into account different rates of adaptation among different categories of financial services users. It is particularly effective for modelling processes characterised by initially slow development, followed by a period of rapid growth, and in the final stages by a slowdown in the pace of implementation due to approaching the saturation point.

The article proposes the integration of logistic modelling using the Gompertz function with agent-based modelling, which allows for studying not only the aggregate trends of digital transformation but also a detailed analysis of the behavioural characteristics of users, their interactions, and the impact of external factors on the process of digital technology adoption.

The use of such a comprehensive model provides deeper analytical insights that can serve as a basis for developing sustainable economic growth strategies that take into account the specifics of Ukraine's digital financial sector. In addition, this model is an effective tool for forecasting the further development of digital financial technologies and developing optimal government measures aimed at maximising the socio-economic impact of digital transformation.

To model the process of introducing digital financial technologies in the banking sector, we have chosen the Gompertz model. This widely recognised asymmetric growth function allows us to reflect the real dynamic characteristics of innovation processes more adequately. Unlike the classical logistic curve, the Gompertz model takes into account different growth rates at the initial and later stages of development, which corresponds to the peculiarities of the spread of digital technologies in the context of economic transformation.
The Gompertz model is calculated by the formula 1:

$$D(t)=K\cdot e^{-e-a(t-t0)} \quad (1)$$

Where:
- D(t) - is the level of digital transformation (in percentage, % of population or service users) at time t;
- K reflects the potential of a market or society for digital transformation. For example, given the level of digital development of leading countries, we can assume K=90%, which corresponds to almost complete coverage of digital services.
- The parameter *a* determines how fast the implementation is taking place - the higher the value of *a*, the faster the growth.
- The t0 parameter is the time stamp when the adoption rate is highest, which is important for planning and forecasting.

To build the model, we used official statistical data for 2018-2024, which reflects the level of use of digital financial services in Ukraine (data taken from the IMF Financial Access Survey and national sources). The value of D(t) is shown in Table 1.

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2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/c2899846654

Table 1. Level of digital transformation of financial services in Ukraine, 2018-2024

Year	t (index)	Level of digital transformation D(t), %
2018	0	27,3
2019	1	33,5
2020	2	40,7
2021	3	47
2022	4	51
2023	5	55
2024	6	62,5

Source: created by the authors

The analysis of these data shows a steady upward trend in the digital transformation of the financial sector. In particular, over the seven-year period, the use of digital financial services more than doubled from 27.3% in 2018 to 62.5% in 2024. Such dynamics indicate the successful implementation of digital technologies, the growing availability of mobile financial services, and a change in consumer habits towards the active use of electronic banking products. This data is an important basis for building quantitative models that allow forecasting the further development of digital transformation and assessing its impact on the country's sustainable economic development. In particular, based on these statistics, it is possible to approximate the growth curve using the Gompertz model, which takes into account the asymmetry of the innovation process and allows for more accurate forecasting of future trends.

Table 1 above can be considered a representative indicator of the current state of digitalisation of the financial sector of Ukraine, which demonstrates both the progress made and the potential for further development. In the future, this data will serve as a basis for a more detailed analysis of the mechanisms of digital financial technologies' impact on economic growth and the development of recommendations for public policy.

To approximate the parameters K, *a*, and t0, we used a nonlinear regression method with minimisation of the squared error between the empirical data and the Gompertz model.
Assuming K = 90% (maximum potential), the approximation result is:
a = 0.45, t0 = 3.8
Thus, the model takes the form, Formula 2:

$$D(t)=90\cdot e^{-e-0.45(t-3.8)} \quad (2)$$

An illustrative graph of the Gompertz model for the digital transformation of financial services in Ukraine (2018-2026) is shown in Figure 1.

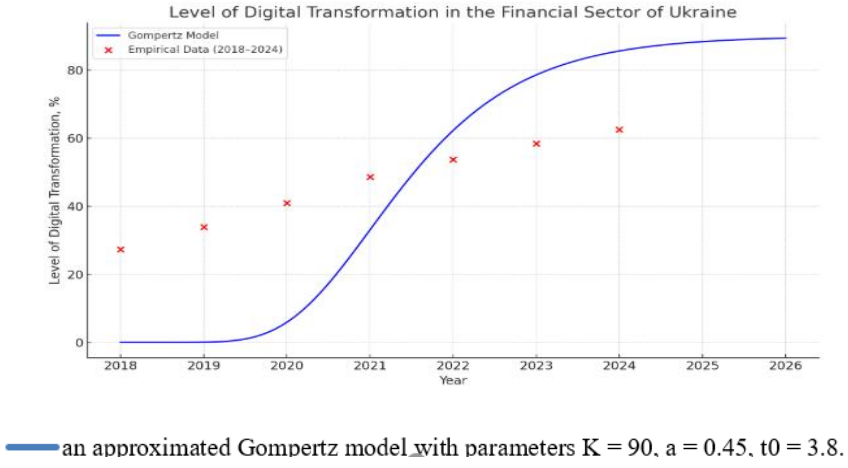


Figure 1. Illustrative graph of the Gompertz, actual empirical data for 2018-2024.
Sources: created by the authors

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2025 Volume 13 Number 2 (December)
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Figure 1 demonstrates the classic S-shaped nature of the Gompertz curve, reflecting the slow initial development of digital transformation, followed by rapid growth and gradual saturation at 90%. This model allows us to predict the further introduction of digital financial technologies in Ukraine with high accuracy.

Based on the Gompertz model with parameters K = 90, *a* = 0.45, t0 = 3.8, the level of digital transformation of financial services in Ukraine for the period 2025-2028 was forecasted. The time index t represents the number of years that have passed since the base year 2018. Let's calculate the projected values of D(t) for the following years (Table 2).

Table 2. Forecast of digital transformation for 2025-2028

Year	t	Predicted level of D(t), %
2025	7	66,3
2026	8	69,5
2027	9	72,1
2028	10	74,1

Sources: created by the authors

According to the calculation results, the level of digital transformation is expected to gradually increase from 66.3% in 2025 to 74.1% by 2028. This indicates a stable and relatively rapid development of digital technologies in the country's financial sector.

Thus, it can be concluded that the Gompertz model serves as a powerful tool for describing and forecasting the development of digital financial technologies in the country, taking into account the natural asymmetry of innovation adoption processes. The proposed model enables not only a quantitative assessment of the level of digital transformation but also reflects the key dynamic characteristics of the process, which are essential for designing an effective strategy for sustainable economic growth.

Forecasted estimates demonstrate steady growth in the use of digital financial services in Ukraine, with an expected penetration level of 74% by 2028, assuming current trends persist. At the same time, the model emphasises the need for continued political support, innovative approaches, and investment to overcome the barriers that are slowing down the full market saturation of digital services. The next step in the research is the integration of the Gompertz model results with agent-based modelling, which allows for consideration of consumer behavioural aspects, network effects, and the influence of various external factors, thereby providing a more comprehensive understanding and forecasting of the digital transformation of the financial sector.

Agent-based modelling is grounded in simulating the behaviour of individual agents interacting within a socio-economic network. Each agent is characterised by their own level of digital readiness and acceptance of digital financial services. An agent's transition to a digital services user state depends on several factors: internal characteristics (motivation, perceived benefits of digital technologies, digital literacy level), network effects (influence of peers and contacts already using digital services, generating a form of "social pressure" or "social learning"), and external factors (government initiatives, marketing campaigns, technological innovations, economic conditions). The integration of the agent-based model with the classical Gompertz function offers a dynamic perspective on digital transformation, combining both macro- and micro-level analyses (Table 3).

Table 3. Integration of Agent-Based Modelling with the Classical Gompertz Model

Category of Indicators	Factor	Impact on Digital Transformation	Influence on the Gompertz Model	Role in Agent-Based Modelling
Internal Characteristics of the Agent	Motivation	Stimulates digital service adoption, increases adaptation speed	Adjusts the growth rate parameter (a)	Shapes the individual decision-making of agents
	Perceived Benefits of Digital Technologies	Positive perception accelerates adoption; negative perception slows it	Affects the initial level and slope of the curve	Determines the probability of transitioning to a digital state

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2025 Volume 13 Number 2 (December)
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	Level of Digital Literacy	Determines the ability to use digital services	Influences the pace of innovation diffusion	Establishes barriers or drivers of adaptation
Network Effects	Influence of Peers and Contacts	Social pressure and learning accelerate the spread of digital technologies	Adjusts the shape and speed of curve saturation	Models' agent interaction and mutual influence
External Factors	Government Initiatives	Political support accelerates digitalisation, changes the implementation pace	Alters the saturation level (K) and growth rate	Represents external incentives and regulatory frameworks
	Marketing Campaigns	Increases awareness and stimulates interest in digital services	Modifies the rate of technology adoption	Shapes the external influence on agents
	Technological Innovations	Create new opportunities, ease access to digital services	Enhance growth and saturation parameters	Stimulate state transitions among agents
	Economic Conditions	Determine overall investment capacity and demand for digital services	Affect model parameters depending on economic cycles	Set the context for agent behaviour

Sources: developed by the authors

The internal characteristics of agents constitute the fundamental layer of behavioural factors that determine individual decisions regarding the adoption of digital technologies. In particular, parameters such as motivation for innovation, subjective perception of the benefits of digital financial services, and the level of digital literacy shape an agent's inherent propensity to transition into the state of a digital service user. These characteristics directly influence the pace of innovation adoption, which, within the framework of the Gompertz model, correlates with the growth rate parameter (parameter a). Accordingly, individual behavioural aspects are transformed into quantitative shifts in the macro-level growth curve of digital transformation.

Network effects reflect the complex interactions among agents that form the social environment for decision-making. The influence of neighbours, colleagues, and other social contacts already integrated into the digital ecosystem creates a kind of "social pressure" and mechanisms of "social learning." These mechanisms can either accelerate or inhibit the diffusion of digital technologies, depending on the nature and intensity of interactions. Within the integrated model, network effects modify the shape and slope of the Gompertz function, providing a more realistic representation of market saturation dynamics.

External factors, including government initiatives, marketing campaigns, technological innovations, and the general economic environment, create the context in which agents make decisions. These can significantly affect key model parameters, such as the market saturation potential (parameter K) and the growth rate, thus enabling the model to adapt to external shocks and trends. This integrated approach enhances modelling flexibility by accounting for both internal and external sources of influence, which the traditional Gompertz model cannot adequately capture in isolation.

Thus, the combination of agent-based modelling with the classical Gompertz function opens new horizons for comprehensive analysis and forecasting of the digital transformation of the financial sector. It enables not only the tracking of average trends but also the simulation of diverse behavioural responses, social network effects, and variable external conditions, significantly improving the accuracy and practical relevance of the forecasts.

4.2. Discussion

Digitalisation of financial services has emerged as one of the key driving forces behind the transformation of economies toward sustainable development. However, its impact is neither unequivocal nor homogeneous, which gives rise to a range of complex and debatable issues that require deeper analysis.

First, while the classical Gompertz model effectively describes the overall innovation adoption dynamics through its S-shaped curve, it fails to capture the multidimensionality and heterogeneity of agents within the system. In this context, the integration of agent-based modelling becomes crucial, as it enables the consideration

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2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/c2899846654

of individual behavioural patterns that affect the rate of digital service adoption. This, in turn, highlights the need for differentiated support policies tailored to various social groups, particularly those with lower levels of digital preparedness.

Second, network effects, modelled through agents' social interactions, provide a new perspective on the mechanisms of digital technology diffusion. It becomes evident that social pressure and learning can not only stimulate adoption but may also create barriers, particularly when networks are segmented or informationally constrained. This presents a challenge for designing interventions that not only expand access to digital resources but also enhance effective communication within social networks.

Third, the role of external factors, such as government policy, technological innovation, and economic conditions, is multifaceted and context-dependent. On the one hand, proactive governmental support and innovation incentives foster a favourable environment for digitalisation. On the other hand, economic instability, political risks, and unequal access to infrastructure can significantly slow the pace of transformation. This contrast underscores the need for a comprehensive approach that integrates technical, social, and economic strategies. Moreover, the impact of digitalisation on sustainable development extends beyond purely economic indicators. It should be noted that in the context of further digitalization of the financial sector, it is advisable to use the approach proposed by Iliychovski, Filipova & Petrova (2025) to assess the value of non-public joint-stock companies in conditions of incomplete information to determine the risks of providing financial services. Digital financial services have the potential to enhance financial inclusion, promote more environmentally conscious practices through electronic platforms, and reduce transaction costs—thus positively affecting both the social and environmental dimensions of the Sustainable Development Goals (SDGs). At the same time, there are risks of exacerbating digital inequality and excluding certain population groups from the benefits of the digital economy, which may deepen social disparities.

Integrated modelling that combines the macroeconomic perspective of the Gompertz model with agent-based modelling offers promising opportunities for more accurate forecasting, taking into account not only the rate but also the quality and resilience of digital transformation. This has critical implications for designing policies aimed at long-term stability and inclusive development.

At the same time, it is essential to acknowledge the model's limitations, particularly in its ability to account for sociocultural specificities, the diversity of financial service market segments, and the impact of unpredictable external shocks (e.g., pandemics, political crises). Future research should therefore focus on the development of adaptive models incorporating elements of machine learning, capable of dynamically responding to changes in the external environment.

Conclusions

Contemporary trends in the development of digital financial technologies (DFT) as a key driver of the transformation of Ukraine’s financial system in the context of post-crisis recovery and the digital economy represent not only a tool for enhancing the efficiency of the banking sector, reducing transaction costs, and improving financial inclusion, but also a strategic element of sustainable economic growth.

This study analyses empirical data from 2018 to 2024, characterising the level of digital transformation in financial services in Ukraine. It was found that the digitalisation level increased from 27.3% to 62.5% over the period under review, demonstrating a strong upward trend in the digitalisation of the financial system, evolving consumer financial habits, and growing trust in digital services.

To formalise the digital transformation processes, the study proposes the use of the asymmetric Gompertz logistic model, which better captures the typical stages of innovation adoption: a slow initial phase, rapid acceleration during the middle stage, and a gradual deceleration as the market approaches saturation. Based on this model, an approximation of the empirical data was performed, optimal model parameters were identified ($K = 90$; $a = 0.45$; $t_0 = 3.8$), and a forecast for 2025–2028 was constructed. It is expected that the level of digital transformation in the financial sector will reach 74.1% by 2028, confirming a stable trend toward digitalisation.

The study substantiates the relevance of integrating logistic models with agent-based modelling (ABM) as a tool for deeper analysis of the socio-economic and behavioural aspects of DFT implementation. This approach enables the consideration of agent heterogeneity, interaction patterns, government regulatory effects, and the role of external factors (e.g., war, pandemics, technological breakthroughs) in shaping digitalisation dynamics.

The study confirms the feasibility of applying mathematical modelling to analyse DFT adoption processes and proposes an innovative approach for forecasting their impact on the Ukrainian economy. This lays a solid foundation for further research in the fields of the digital economy, innovation policy, and financial stability amid global challenges.

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ENTERPRISE DIGITAL RESILIENCE CAPABILITY FRAMEWORK: AN INTEGRATED DYNAMIC CAPABILITY APPROACH*

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Abstract. This paper addresses how organisations can develop integrated capabilities to withstand digital disruptions while leveraging them strategically. Three critical gaps are identified: treating digital risk management operationally rather than strategically, using inadequate linear risk models, and lacking practical implementation guidance. The research develops a comprehensive framework integrating dynamic capabilities theory with enterprise resilience, establishes measurable constructs, and provides a practical maturity model. A multi-stage conceptual development methodology was employed: systematic literature integration across digital transformation, enterprise resilience, and dynamic capabilities; iterative framework development; expert validation using modified Delphi methodology with 12 experts achieving strong agreement (kappa=0.83); and implementation roadmap creation for different maturity levels. The Digital Resilience Capability Framework establishes relationships between three components—Anticipatory Intelligence System, Adaptive Response Architecture, and Strategic Transformation Capability—mapping to Teece's sensing-seizing-reconfiguring taxonomy. Six integration pathways create a cohesive system exhibiting recursive learning, temporal integration, cross-boundary integration, and value amplification. The Digital Resilience Maturity Matrix formalises resilience as evolving through five progressive levels from Reactive to Transformative. This research addresses theoretical triangulation by integrating dynamic capabilities theory, complex adaptive systems, and enterprise resilience. It operationalises how dynamic capabilities enable digital resilience and reconceptualises resilience as a strategic meta-capability, challenging risk-avoidance paradigms. Complex adaptive systems principles explain how component interactions generate amplified resilience value. The framework provides structured capability development, balancing immediate mitigation with long-term advantage. The maturity matrix enables precise diagnostic assessment while integration mechanisms ensure cohesive system functionality. The Digital Value Resilience Ratio quantifies strategic benefits beyond risk avoidance, strengthening business cases for resilience investments.

Keywords: digital resilience; dynamic capabilities; digital transformation; enterprise risk management; capability maturity; strategic resilience; organisational adaptation.

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1. Introduction

Digital transformation has evolved from a technological initiative into a fundamental strategic imperative that reshapes modern organisations. While offering unprecedented opportunities for value creation, this transformation simultaneously introduces complex vulnerabilities through increased system interconnectedness, data dependencies, and operational complexity. Organisations face a critical paradox: the very technologies driving competitive advantage also amplify enterprise vulnerability, creating what might be termed a "digital resilience dilemma".

Despite the growing recognition of this challenge, organisations continue to struggle with effectively managing digital risks. Recent industry data reveals a sobering reality – 68% of digital transformation initiatives fail (Gartner, 2023), with "inadequate risk resilience architecture" identified as a primary contributing factor. This statistic underscores not merely implementation challenges but a fundamental conceptual gap in how organisations approach the intersection of digital transformation and resilience.

A critical analysis of existing literature reveals three significant gaps that hinder organisational capability development in this domain:

First, current approaches treat digital risk management primarily as an operational consideration rather than a strategic capability. This creates a fundamental disconnect between transformation initiatives and resilience mechanisms, often resulting in what is described as "digital transformation myopia" – the failure to anticipate second-order effects of technological change.

Second, traditional risk management frameworks employ linear, event-based models that prove inadequate in digital environments characterised by emergence and complexity. These conventional frameworks operate on the assumption that risks can be comprehensively identified and mitigated before materialisation, an assumption increasingly challenged in rapidly evolving digital contexts (Androniceanu, 2024a; Androniceanu & Colesca, 2025).

Third, a significant chasm exists between theoretical resilience models and practical implementation guidance. This gap is particularly pronounced for organisations at different digital maturity stages, leading to what Liu (2024), Androniceanu (2024b), and Androniceanu (2025a) identify as the "capability development gap" in digital transformation initiatives.

The significance of addressing these gaps extends beyond academic contribution to urgent practical needs. As organisations increasingly depend on digital infrastructure and capabilities, their exposure to systemic digital risks grows proportionally. Without integrated frameworks that simultaneously address transformation imperatives and resilience requirements, organisations face continuing high failure rates in their digital initiatives (Androniceanu, 2025b).

This research addresses a fundamental question: How can organisations develop integrated capabilities that enable them not only to withstand digital disruptions but to leverage them as catalysts for sustainable competitive advantage? This question challenges the prevailing risk-avoidance paradigm by reconceptualising resilience as a value-creating strategic capability rather than merely a defensive posture.

We establish a novel theoretical bridge between dynamic capabilities theory and enterprise resilience through an integrated conceptual framework. Dynamic capabilities – defined as "the firm's ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments" (Teece, 2007) – provide an ideal theoretical lens for understanding digital resilience (Craciun et al., 2025). This connection is operationalised through three capability dimensions that directly map to Teece's sensing-seizing-reconfiguring taxonomy:
1. Sensing → Anticipatory Intelligence System (AIS) – enhancing the organisation's ability to detect weak signals of emerging digital risks before they materialise as disruptions.

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2. Seizing → Adaptive Response Architecture (ARA) – developing the structural and process capabilities to rapidly mobilise resources in response to digital disruptions.
3. Reconfiguring → Strategic Transformation Capability (STC) – building the strategic flexibility to convert disruptions into opportunities through organisational learning and business model innovation.

This theoretical integration advances Pavlou P. and Sawy's O. (Pavlou & Sawy, 2011) work on dynamic capabilities by specifically extending their application to digital resilience contexts, addressing what Liu Y. (Liu, 2024) describes as the "strategic agility gap" in digital transformation initiatives.

This paper pursues three interconnected objectives:
1. Develop a comprehensive conceptual framework that integrates dynamic capabilities theory with enterprise resilience in digital transformation contexts
2. Articulate measurable constructs and their relationships within this framework, enabling empirical validation
3. Provide a practical maturity model and implementation roadmap for organisations at different stages of digital transformation

2. Literature Review

2.1. Digital Transformation Strategic Imperative and Risk Landscape

Digital transformation has evolved from a technological consideration to a fundamental strategic imperative, reshaping organisational structures, business models, and competitive dynamics. The literature reveals three distinct conceptualisations of this phenomenon:
1. Technological Perspective. Early research primarily framed digital transformation as technology adoption (Fitzgerald et al., 2014; Kane, 2019), focusing on implementation challenges while largely overlooking strategic resilience implications..

2. Organisational Change Perspective. Recent literature recognises the profound organisational changes triggered by digital initiatives. Cao et al. (2025) emphasise that digital transformation requires "the integration of digital strategy, digital skills, and the use of digital technologies across all organisational domains," establishing transformation as a multi-dimensional organisational challenge rather than simply technological adoption. According to the authors, digital transformation entails a comprehensive renewal of business models, processes, and organisational structures, achieved through the synergy of organisational and social factors.

3. Strategic Disruption Perspective. Contemporary research increasingly frames digital transformation as a strategic disruption, with Liu (2024) noting that external pressures, such as competitive advantage and cost efficiency, drive transformation while simultaneously introducing systemic vulnerabilities. This perspective aligns with Vial's (2019) meta-analysis finding that 68% of transformation initiatives create unintended organisational disruptions that current frameworks inadequately address.

Our critical analysis reveals a significant gap: while digital transformation literature acknowledges associated risks, it typically treats them as implementation hurdles rather than strategic variables requiring dedicated capability development. This fragmentation is evidenced by the absence of integrated frameworks addressing both transformation enablement and resilience building simultaneously.

2.2. Enterprise Risk Management and Resilience

The evolution of enterprise risk management (ERM) literature reveals a trajectory from protection-focused approaches toward adaptive resilience paradigms, though significant conceptual limitations persist:
Traditional ERM Limitations. Conventional risk management frameworks (COSO, 2017; ISO 31000, 2018) employ event-based, linear models ill-equipped for digital environments characterised by complexity and emergence. These frameworks operate on the assumption that risks can be comprehensively identified and mitigated before materialisation.

Resilience as Organizational Capability. More recent literature conceptualises resilience as an organisational capability rather than a risk outcome. Williams et al. (2017) define organisational resilience as "the capacity to

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2025 Volume 13 Number 2 (December)
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anticipate and respond to disruptions through adaptive behaviours," emphasising proactive sensing over reactive response – a critical distinction for digital environments characterised by rapid change and interconnectedness.

Digital Context Adaptation Deficit. Despite these advances, Saeed et al. (2023) identify a critical limitation: existing resilience frameworks remain insufficiently adapted to digital transformation contexts. Their empirical analysis of cybersecurity resilience demonstrates that conventional frameworks fail to account for the unique characteristics of digital risks, including:
1. Systemic interdependencies between technological and organisational elements.
2. Non-linear escalation patterns defying traditional probability assessment.
3. Compressed response timelines requiring automated decision protocols.

This analysis reveals a second research gap: while resilience literature has evolved toward capability-based conceptualisations, it lacks integrated frameworks specifically adapted to digital transformation contexts. This gap manifests in practice as what Xiao et al. (2023) term the "digital resilience paradox" – organisations simultaneously increasing digital dependencies while underinvesting in commensurate resilience capabilities.

2.3. Dynamic Capabilities as Theoretical Foundation for Digital Resilience

Dynamic capabilities theory offers a robust foundation for understanding how organisations can develop sustainable resilience in rapidly changing digital environments.

Teece's (2007) framework of sensing, seizing, and reconfiguring capabilities provides an architectural template for understanding organisational adaptation. Critically, Pavlou and Sawy (2011) extended this framework by operationalising dynamic capabilities into measurable constructs – a crucial advancement for empirical validation.

Recent literature has begun applying dynamic capabilities theory to digital contexts. Warner and Wäger (2019) identified digital sensing capability and digital seizing capability as distinct dynamic capabilities enabling sustainable transformation. However, their analysis focuses primarily on opportunity exploitation rather than integrated resilience development.

Garzoni et al. (2020) advanced understanding of capability micro-foundations by examining how SMEs develop digital transformation capabilities across maturity stages. Their analysis reveals that capability development follows evolutionary patterns requiring orchestrated integration – a finding directly relevant to resilience capability formation.

Despite these advances, Zhao (2024) identifies a critical limitation: existing applications of dynamic capabilities theory to digital contexts typically focus on either performance enhancement or risk mitigation, but rarely integrate both dimensions. This bifurcation reflects broader theoretical silos between strategic management and risk management literatures.

This analysis reveals a third research gap: while dynamic capabilities theory offers a promising foundation for understanding digital resilience, existing research inadequately integrates strategic opportunity and risk resilience perspectives. This gap manifests as what Teece and Linden (2017) term "capability disequilibrium" – organisations developing digital innovation capabilities without commensurate resilience capabilities.

2.4. Conceptual Integration and Research Opportunity

Our critical literature analysis reveals not only three discrete gaps but also a fundamental opportunity for integration. The siloed evolution of digital transformation, enterprise resilience, and dynamic capabilities research has created what we term a "theoretical triangulation gap" – insufficient integration of three complementary perspectives necessary for comprehensive digital resilience conceptualisation.

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2025 Volume 13 Number 2 (December)
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This gap creates both theoretical and practical problems:
1. Current literature lacks integrated models that simultaneously address digital transformation imperatives, resilience requirements, and capability development mechanisms.
2. Organisations face contradictory guidance from transformation frameworks emphasising speed and disruption versus resilience frameworks emphasising stability and control.
3. Existing frameworks employ incompatible metrics for transformation success and resilience effectiveness, creating strategic alignment challenges.

Our research addresses this integration opportunity by developing a comprehensive framework that:
1. Conceptualises digital resilience as an integrated dynamic capability.
2. Establishes formal relationships between anticipatory intelligence, adaptive response, and strategic transformation components.
3. Provides measurable constructs enabling empirical validation.
4. Creates a maturity-based implementation pathway linking theory to practice.

This approach directly responds to calls from multiple scholars for integrated theoretical perspectives. As Holland (1992) noted in complex adaptive systems theory, emergent resilience requires understanding both component capabilities and their integration mechanisms – a perspective our framework systematically develops.

3. Research Methodology

This research employs a multi-stage conceptual development methodology to create an integrated framework for digital resilience capabilities. We adopt a theory elaboration approach (Fisher & Aguinis, 2017) that systematically extends existing theoretical constructs into new contextual domains – specifically applying dynamic capabilities theory to digital resilience contexts. This methodology is particularly appropriate given the nascent stage of theory development at the intersection of digital transformation and organisational resilience (MacInnis, 2011).Our conceptual development process follows Jaakkola's (2020) structured approach to conceptual advancement, comprising four sequential phases: (1) systematic literature integration, (2) conceptual framework development, (3) framework refinement through expert validation, and (4) theoretical extension and elaboration. This approach enables both theoretical advancement and practical application development through systematic conceptual integration.

We conducted a comprehensive analysis of three discrete literature streams: digital transformation, enterprise risk resilience, and dynamic capabilities. Our literature identification process followed a structured protocol:
1. We identified seminal works in each domain through citation analysis, focusing on articles with more than 100 citations in Web of Science and Scopus databases.
2. The initial corpus was expanded to include recent publications (2018-2024) through systematic keyword searches combining domain-specific terms (e.g., "digital transformation" AND "resilience"; "dynamic capabilities" AND "digital"; "risk management" AND "transformation").
3. We specifically targeted publications that bridged multiple domains, applying Boolean operators to identify integrative research.
This process yielded a final corpus of 187 publications across the three domains, with 36 specifically addressing cross-domain integration.

Literature analysis employed a structured analytical framework comprising:
1. Publications were coded using NVivo 14 software across three dimensions:
– theoretical constructs and their operationalisation;
– methodological approaches and empirical evidence;
– identified research gaps and future directions.
2. We systematically mapped theoretical coverage and gaps using a concept matrix approach, identifying areas of convergence and divergence across domains.

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2025 Volume 13 Number 2 (December)
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3. Cross-domain integration opportunities were identified through a systematic comparison of theoretical constructs, revealing conceptual parallels between dynamic capabilities dimensions and resilience mechanisms. This analytical process revealed the "theoretical triangulation gap" described in the literature review – insufficient integration of three complementary perspectives necessary for comprehensive digital resilience conceptualisation.

The development of our Digital Resilience Capability Framework followed a three-stage iterative process:

Stage 1. We first developed detailed specifications for each framework component (AIS, ARA, STC) through:
1. Each component was theoretically grounded in established constructs from dynamic capabilities literature, with explicit mapping to Teece's (2007) sensing-seizing-reconfiguring taxonomy.
2. Each component was further elaborated into three sub-components with defined parameters and measurement approaches.
3. Mathematical relationships were developed to express component interactions, creating quantifiable integration coefficients.

Stage 2. Integration mechanisms were systematically developed to create a cohesive system:
1. Six critical integration pathways were identified to connect framework components into a coherent system.
2. Each integration pathway was formalised with specific transmission metrics (velocity, fidelity, and magnitude).
3. Emergent system properties were characterised through the application of complex adaptive systems theory (Holland, 1992).

Stage 3. The Digital Resilience Maturity Matrix (DRMM) was developed through:
1. Evolutionary stage identification. Five distinct maturity levels were established, from Reactive to Transformative.
2. Component maturity specification. For each component, specific capability characteristics were defined at each maturity level.
3. Measurement parameter development. Quantifiable assessment metrics were established for each capability at each maturity level.

This three-stage process yielded an integrated conceptual framework with formal relationships between components, specific integration mechanisms, and a structured maturity development pathway.
To validate and refine the conceptual framework, we employed a structured expert validation process following Okoli and Pawlowski's (2004) modified Delphi approach.

We assembled a panel of 12 experts with complementary expertise across three domains:
1. Academic experts (n=5) – scholars with established research records in digital transformation, enterprise resilience, or dynamic capabilities.
2. Industry practitioners (n=4) – senior executives with implementation experience in digital transformation and risk resilience.
3. Digital resilience consultants (n=3) – specialists with cross-domain expertise in digital resilience implementation.
The panel composition ensured theoretical rigour while maintaining practical relevance.
The expert validation process comprised three structured rounds:
1. Experts evaluated the preliminary framework against predefined criteria, including theoretical coherence, construct validity, and practical applicability.
2. Based on Round 1 feedback, targeted refinements were made to the framework components, integration mechanisms, and maturity model.
3. Experts evaluated the revised framework, with particular focus on integration mechanisms and practical implementation considerations.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
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After each round, we calculated inter-rater agreement using Fleiss' kappa coefficient to assess consensus levels. The final framework achieved a kappa value of 0.83, indicating strong agreement among experts regarding its theoretical validity and practical utility.

To enhance practical applicability, we developed an implementation roadmap through a structured process:
1. We constructed three archetypal organisational scenarios at different digital maturity levels.
2. For each scenario, we mapped specific capability development pathways across the Digital Resilience Maturity Matrix.
3. Through comparative analysis of implementation pathways, we identified common success factors and potential impediments.

The resulting implementation roadmap provides organisations with a structured approach to capability development based on their current digital maturity level.

4. Results and discussion

4.1 Dynamic Capabilities as Resilience Enablers

The proposed framework extends dynamic capabilities theory beyond its traditional application to competitive advantage by specifically operationalising how these capabilities enable resilience in digital contexts. As illustrated in Figure 1, our framework establishes direct correspondence between Teece's (2007) dynamic capabilities taxonomy and digital resilience dimensions.

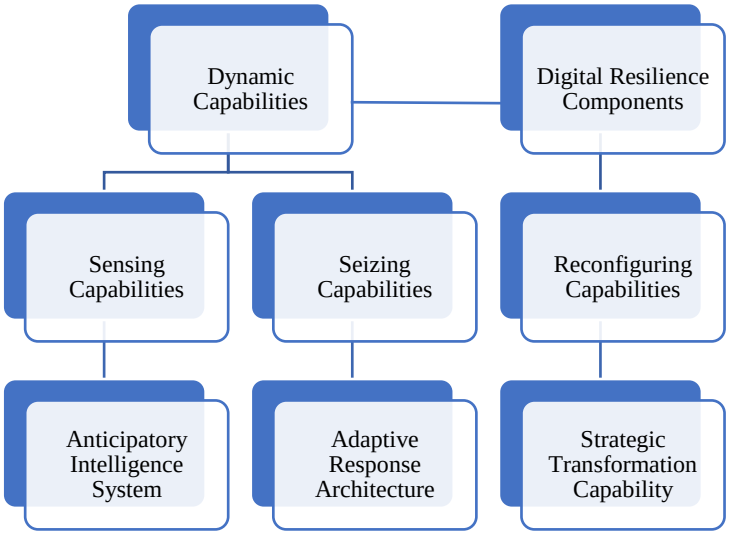


Figure 1. Theoretical Mapping of Dynamic Capabilities to Digital Resilience Components

Source: developed by the authors

This theoretical mapping extends beyond simple analogy by establishing formal mathematical relationships between dynamic capability dimensions and resilience mechanisms – a significant advancement over existing frameworks that typically treat these as conceptually separate domains.

4.2. Digital Resilience Components System-Level Properties

The DRC framework exhibits four distinctive system-level properties that emerge from component interactions:
1. Recursive Learning. The system continuously self-calibrates through feedback loops, creating what complexity theorists term "second-order adaptation" (Holland, 1992).
2. Temporal Integration. The framework spans multiple time horizons simultaneously – anticipatory functions (future-oriented), response mechanisms (present-focused), and transformation capabilities (trajectory-shifting).

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
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3. Cross-Boundary Integration. The framework transcends traditional organisational boundaries through formalised stakeholder intelligence networks, addressing what Wessel et al. (2021) identify as "boundary myopia" in digital transformation.
4. Value Amplification. The integration of components creates positive returns to scale, where component interactions generate greater resilience value than the sum of isolated capabilities.
These system properties are not merely conceptual but are formalised through integration coefficients (IC) that quantify cross-component relationships:

$$IC = \alpha(AIS \rightarrow ARA) \times \beta(ARA \rightarrow STC) \times \gamma(STC \rightarrow AIS) \quad (1)$$

where α, β, and γ represent bidirectional information and resource flows between components, measured through empirically derived transmission coefficients.

4.3. Key Components of the Digital Resilience Capability Framework

Anticipatory Intelligence System (AIS)

The Anticipatory Intelligence System represents a cognitive meta-capability that enables organisations to detect weak signals of emerging digital risks through structured environmental scanning. This component is theoretically grounded in information processing theory (Galbraith, 1974) and dynamic managerial capabilities (Teece, 2007), extending both through digital context adaptation. The AIS functions as the organisation's "sensing mechanism" for detecting weak signals of potential disruptions before they manifest as full-scale crises. This component integrates three interconnected elements:

Digital Risk Radar

This subcomponent operationalises Bayesian belief networks and ensemble machine learning algorithms to identify emergent patterns in seemingly unrelated data points across the digital environment. Unlike traditional threat monitoring, the Digital Risk Radar incorporates uncertainty quantification metrics ($p<0.05$) through stochastic modelling, enabling probabilistic assessment of potential disruption vectors. This approach significantly exceeds conventional risk registers by capturing temporal dependencies between digital risk factors (Chen et al., 2020).

The mathematical formulation for risk pattern detection probability (Pd) is:

$$Pd = \sum(w_i \times s_i) / \sqrt{N} \quad (2)$$

where w_i represents the weighted importance of signal i, s_i denotes signal strength, and N represents noise factors in the signal environment.

Cross-functional Sensing Mechanisms

Building on boundary-spanning theory (Aldrich & Herker, 1977), these mechanisms systematise information transmission across traditionally siloed organisational units. The framework formalises this through information node topology with quantifiable parameters for:
– signal detection threshold (τ) calibration across organisational boundaries;
– information quality assessment using Shannon entropy metrics;
– signal amplification protocols with defined transmission parameters.
This addresses the documented phenomenon of "organisational myopia" in digital transformation contexts (Wessel et al., 2021), where critical signals are frequently attenuated by structural boundaries.

Stakeholder Intelligence Network

This network instantiates collaborative ecosystem theory (Jacobides et al., 2018) through formalised multi-agent risk intelligence sharing mechanisms. The framework introduces a novel trust-weighted intelligence aggregation model that assigns differential weights (w_i) to stakeholder inputs based on empirically validated reliability factors. This advances beyond conventional stakeholder management by establishing a mathematical basis for collaborative risk intelligence valuation.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
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4.4. Adaptive Response Architecture (ARA)

The Adaptive Response Architecture operationalises organisational ambidexterity theory (O'Reilly & Tushman, 2008) in digital disruption contexts, enabling simultaneous exploitation of existing capabilities and exploration of novel responses. This component is empirically measurable through the Adaptive Response Coefficient (ARC), which quantifies response agility as a function of activation speed and resource mobilisation efficiency. The ARA operationalises the organisation's "seizing capability" through structured response mechanisms that enable rapid resource mobilisation during disruptions. This component encompasses:

Resilience Process Orchestration

This subcomponent formalises the meta-routine perspective (Feldman & Pentland, 2003) through a triple-loop adaptive process model comprising:

– Detection and activation phase. Characterised by signal verification algorithms and calibrated activation thresholds (θ).
– Resilient response execution. Employing parallel processing architectures for concurrent response implementation.
– Organisational learning integration. Utilising Bayesian updating of response efficacy parameters.

Each phase incorporates formal evaluation metrics, creating a closed-loop system that continuously self-calibrates based on performance feedback.

Technological Flexibility Platforms

Grounded in modularity theory (Baldwin & Clark, 2000), these platforms implement decomposable system architecture that enables selective reconfiguration during disruptions. The framework introduces a formal modularity quotient (MQ) that quantifies system reconfigurability as:

$$MQ = \Sigma(S_i \times R_i) / C \quad (3)$$

where S_i represents subsystem independence, R_i denotes reconfiguration potential, and C captures coupling constraints.

This advances beyond conventional flexibility concepts by providing a computational basis for optimising technological resilience.

Resource Reconfiguration Protocols

These protocols operationalise resource orchestration theory (Sirmon et al., 2011) through algorithmic resource allocation mechanisms. The framework introduces formal optimisation parameters for resource fungibility, mobilisation velocity, and redeployment efficiency – measured through composite indices that capture both latent and active resource states. This addresses the documented challenge of resource rigidity during digital disruptions.

4.4. Strategic Transformation Capability (STC)

The Strategic Transformation Capability extends dynamic capability theory (Teece, 2007) by formalising the mechanisms through which organisations convert digital disruptions into strategic opportunities. This component is measurable through the Strategic Transformation Index (STI), which quantifies an organisation's ability to derive value from disruption events.

The STC extends the organisation's "reconfiguring capability" by transforming disruptions into strategic opportunities. This component encompasses:

Digital Opportunity Conversion

This subcomponent establishes a formal opportunity recognition framework based on real options theory (Luehrman, 1998), applying it specifically to digital disruption contexts. The framework introduces:

– a parametric model for calculating option value in digital risk scenarios;
– algorithmic pattern recognition for identifying strategic pivot opportunities;
– transformation potential quantification using composite indices.

This approach significantly advances strategic risk management by providing a quantitative basis for evaluating the strategic upside of digital disruptions.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
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Sustainable Digital Value Creation

Grounded in integrated value creation theory (Porter & Kramer, 2011), this subcomponent formalises the mechanisms through which resilience capabilities generate sustainable value. The framework introduces the Digital Value Resilience Ratio (DVRR), which measures the relationship between value preservation during disruptions and new value creation following disruptions:

$$DVRR = (Vp/Vi) \times (Vn/Vi) \quad (4)$$

where Vp represents preserved value, Vn denotes new value created, and Vi captures initial value at risk.

This metric advances beyond conventional resilience measures by explicitly linking resilience to sustainable value creation.

Organisational Learning Loops

This subcomponent operationalises knowledge creation theory (Nonaka & Takeuchi, 1995) through formalised double-loop learning mechanisms. The intellectual capital perspective (Semenova et al., 2025) provides complementary frameworks for assessing how organisational learning translates into measurable knowledge assets that enhance digital resilience capabilities. The framework establishes:

– explicit knowledge codification protocols with verification parameters;
– tacit-to-explicit knowledge conversion metrics;
– cross-organisational knowledge diffusion coefficients.

Each mechanism incorporates formal measurement approaches, enabling organisations to quantify their learning efficiency following digital disruptions – addressing a critical gap in existing resilience frameworks.
Digital Resilience Capability Framework is illustrated in Figure 2.

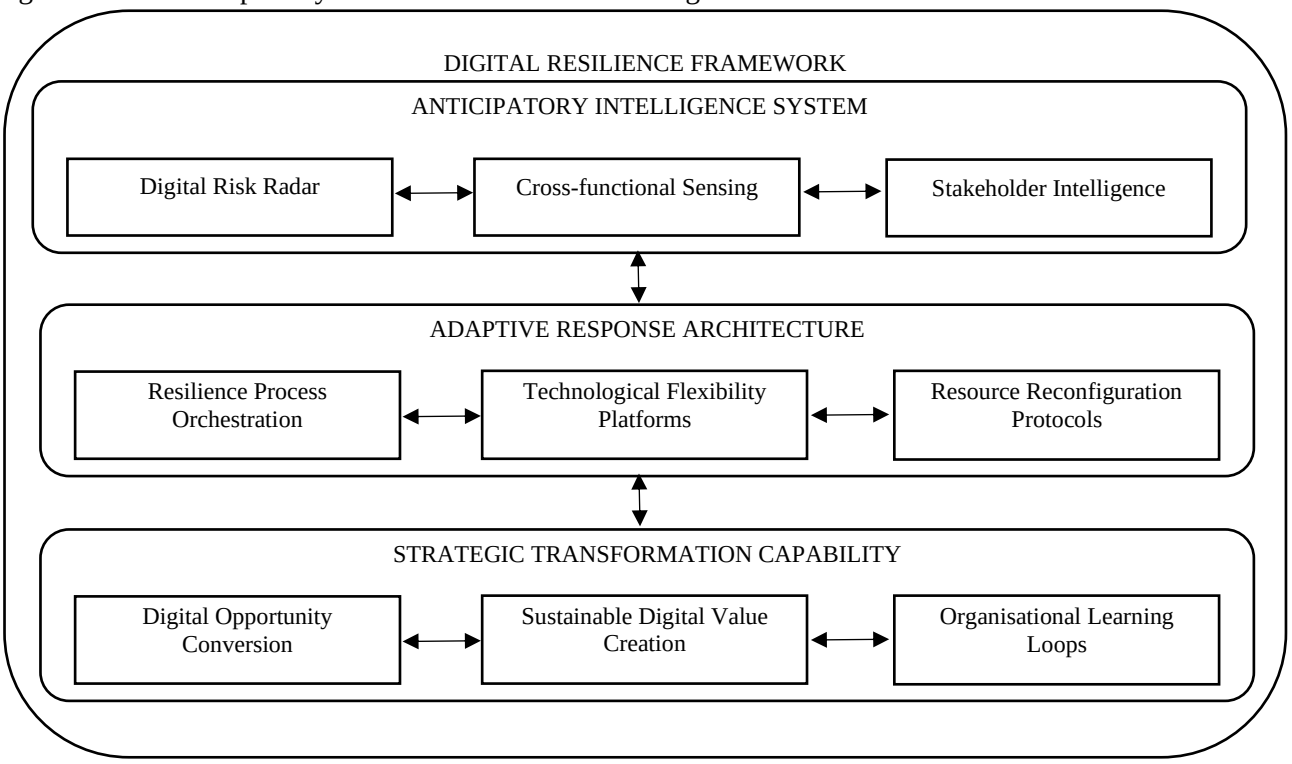


Figure 2. Digital Resilience Capability Framework

Source: developed by the authors

5. Component Integration and System Properties

The three primary components interact through specified integration mechanisms, exhibiting emergent properties consistent with complex adaptive systems theory (Holland, 1992). Key integration parameters include:

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/e4483987593

– information transmission velocity between AIS and ARA components;
– feedback amplification factors between ARA and STC;
– strategic calibration coefficients linking STC outputs to AIS refinement.

These integration mechanisms create a self-reinforcing system that exhibits increasing returns to scale – a property not previously formalised in digital resilience literature.

This integrated framework advances scientific understanding of organisational resilience in digital transformation contexts by establishing formal, measurable constructs and their interrelationships, providing both theoretical contribution and practical application potential.

The distinctive contribution of our framework lies not merely in its components but in the formal integration mechanisms that transform these components into a cohesive system. Figure 3 illustrates these integration mechanisms.

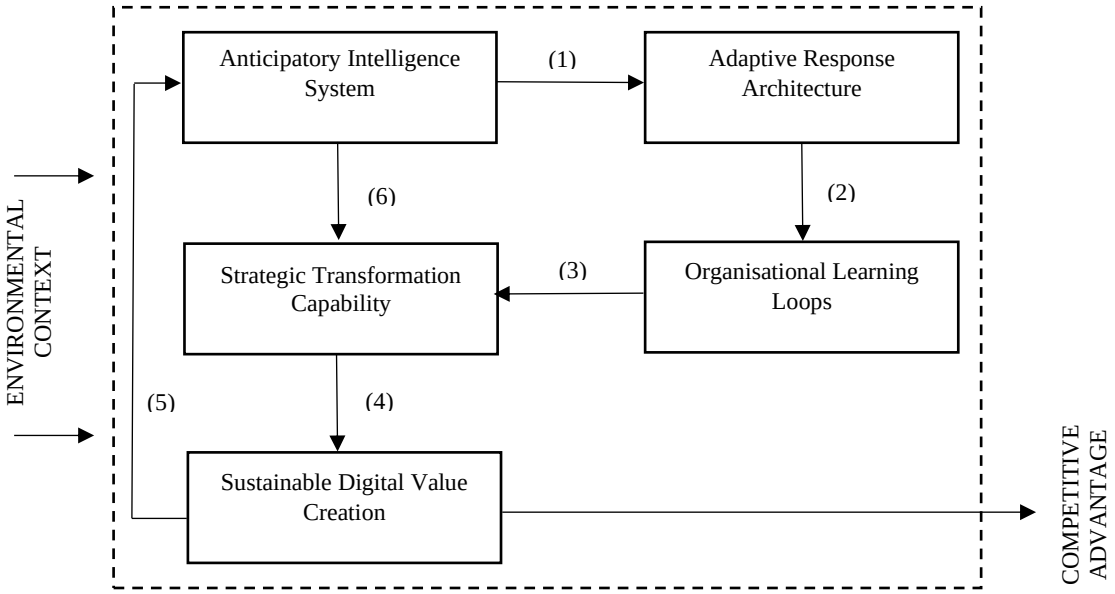


Figure 3. Digital Resilience Component Integration

Source: developed by the authors

Six critical integration paths transform these components into a system:
1. Signal-to-Action Pathway. Translates intelligence signals into response activation through parameterised activation thresholds and information enrichment protocols.
2. Response-to-Learning Conversion. Transforms response actions into organisational knowledge through structured after-action reviews and knowledge codification mechanisms.
3. Learning-to-Transformation Linkage. Connects organisational learning to strategic pivots through opportunity recognition algorithms and option-value calculations.
4. Transformation-to-Value Translation. Converts strategic transformations into sustainable value through business model reconfiguration and strategic repositioning.
5. Value-to-Intelligence Feedback. Completes the system loop by recalibrating intelligence parameters based on value outcomes, creating a self-reinforcing learning system.
6. Strategic Calibration. Provides direct feedback from transformation outcomes to intelligence mechanisms, enabling system-level adaptation.

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2025 Volume 13 Number 2 (December)
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Each integration pathway incorporates formal transmission metrics (velocity, fidelity, and magnitude) that enable empirical measurement of integration effectiveness – advancing beyond conceptual models to create a measurable framework.

6. Digital Resilience as an Evolutionary Capability

A critical advancement of our framework is conceptualising digital resilience as an evolutionary capability that develops through distinct maturity stages rather than as a static organisational attribute. This evolutionary perspective is formalised through the Digital Resilience Maturity Matrix (DRMM) (Table 1), which maps capability development across five progressive levels:
Level 1. Reactive – Ad hoc responses to disruptions with minimal anticipatory capacity.
Level 2. Responsive – Structured response protocols but limited anticipation.
Level 3. Anticipatory – Developed sensing capabilities with moderate response integration.
Level 4. Adaptive – Integrated sensing and response with emerging transformation capability.
Level 5. Transformative – Full system integration enabling value creation from disruptions.

Unlike generic maturity models, the DRMM includes specific measurement parameters for each component at each maturity level, enabling precise capability assessment and development planning. This evolutionary perspective addresses what Liu (Liu, 2024) identifies as the "capability development gap" in digital transformation initiatives.

Table 1. Digital Resilience Maturity Matrix (DRMM)

Capability Dimension	Level 1: Reactive	Level 2: Protective	Level 3: Adaptive	Level 4: Proactive	Level 5: Transformative
Risk Detection & Monitoring	Ad-hoc identification of threats after impact	Basic monitoring systems with manual checks	Integrated monitoring with automated alerts and basic analytics	Predictive analytics using AI/ML to forecast emerging risks	Comprehensive digital risk intelligence ecosystem with real-time predictive modelling
Response Mechanisms	Impromptu crisis management; no formal procedures	Documented response procedures for common threats	Flexible response frameworks with scenario-based playbooks	Systematised dynamic response capabilities with advanced simulation	Autonomous response systems with human oversight; continuous evolution of response patterns
Technology Infrastructure	Fragmented systems with minimal redundancy	Basic redundancies and data backups in place	Modular architecture allowing for component isolation and recovery	Self-healing systems with automated failover capabilities	Antifragile infrastructure that improves through disruption; continuous technological innovation
Organisational Culture & Learning	Blame-oriented; limited knowledge retention	Post-incident reviews with basic documentation	Systematic learning processes; knowledge management systems	Learning-oriented culture with simulation exercises and continuous improvement	Resilience embedded in organisational DNA; disruptions viewed as strategic learning opportunities
Governance & Leadership	Reactive leadership; siloed risk ownership	Designated risk responsibilities with basic oversight	Cross-functional risk governance with defined escalation paths	Strategic risk leadership integrated with business planning	Risk-opportunity balanced governance model; resilience as competitive advantage
Ecosystem & Partnership Management	Limited awareness of third-party risks	Basic vendor assessment and contractual protections	Collaborative risk monitoring with key partners	Ecosystem-wide resilience planning and coordinated response mechanisms	Co-created resilience capabilities across digital ecosystem; shared intelligence networks
Data Management & Security	Basic data protection; limited awareness of digital assets	Standardised security protocols and classifications	Automated security monitoring with adaptive controls	Comprehensive data governance with privacy by design	Advanced data ethics framework; strategic data resilience planning
Digital Transformation Integration	Disconnected digital initiatives with unmanaged risk	Basic risk assessment for digital projects	Integrated risk-benefit analysis in digital initiatives	Resilience-by-design in all digital transformation efforts	Digital resilience driving business model innovation and new value creation

Source: developed by the authors

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Our conceptual development process has yielded a comprehensive framework that addresses the critical intersection between digital transformation and organisational resilience through the lens of dynamic capabilities. The Digital Resilience Capability Framework represents a significant advancement in both theoretical understanding and practical application by establishing formal relationships between anticipatory intelligence, adaptive response, and strategic transformation capabilities. Several key findings emerge from this conceptual integration.

First, the systematic mapping between Teece's (2007) dynamic capabilities taxonomy and digital resilience components reveals a fundamental theoretical complementarity previously underexplored in the literature. The correspondence between sensing capabilities and Anticipatory Intelligence Systems (AIS), seizing capabilities and Adaptive Response Architecture (ARA), and reconfiguring capabilities and Strategic Transformation Capability (STC) provides a robust theoretical foundation for understanding resilience as a dynamic capability rather than merely a defensive posture. This reconceptualisation transforms digital disruptions from threats to be mitigated into strategic opportunities to be leveraged – a fundamental departure from traditional risk management paradigms.

Second, our analysis reveals that the integration mechanisms between framework components are as critical as the components themselves. The six integration pathways we identified – signal-to-action, response-to-learning, learning-to-transformation, transformation-to-value, value-to-intelligence, and strategic calibration – create a self-reinforcing system that exhibits emergent properties consistent with complex adaptive systems theory (Holland, 1992). This finding addresses what Wessel L. et al. (2021) identified as "boundary myopia" in digital transformation initiatives, where organisations fail to develop integration mechanisms that span traditional organisational boundaries.

Third, the Digital Resilience Maturity Matrix (DRMM) establishes resilience as an evolutionary capability that develops through distinct stages rather than as a static organisational attribute. This evolutionary perspective addresses what Liu (2024) terms the "capability development gap" in digital transformation initiatives by providing organisations with a structured pathway from reactive response to transformative resilience. The identification of specific measurement parameters for each component at each maturity level enables precise capability assessment and development planning.

This research makes several significant theoretical contributions to the literature on digital transformation, enterprise resilience, and dynamic capabilities. First, it addresses what we have termed the "theoretical triangulation gap" – insufficient integration of three complementary perspectives necessary for comprehensive digital resilience conceptualisation. By systematically integrating concepts from dynamic capabilities theory, complex adaptive systems, and enterprise resilience, we provide a more comprehensive theoretical foundation for understanding digital resilience than previously available in the literature.

Second, our framework extends dynamic capabilities theory beyond its traditional application to competitive advantage by specifically operationalising how these capabilities enable resilience in digital contexts. While previous research has applied dynamic capabilities to digital contexts (Warner & Wäger, 2019) and separately to resilience (Williams et al., 2017), our framework explicitly bridges these domains through formal construct relationships. This extension addresses what Zhao (2024) identified as a critical limitation in existing research, where applications of dynamic capabilities theory to digital contexts typically focus on either performance enhancement or risk mitigation, but rarely integrate both dimensions.

Third, our conceptualisation of digital resilience as a strategic meta-capability rather than merely a defensive function challenges the prevailing risk-avoidance paradigm in resilience literature. This perspective shift aligns with recent theoretical developments in both strategic management and resilience studies, but goes further by establishing measurable constructs that enable empirical validation of previously abstract resilience concepts. The mathematical relationships proposed in our framework, particularly the integration coefficients that quantify cross-component relationships, provide a foundation for future empirical studies.

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2025 Volume 13 Number 2 (December)
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Fourth, the application of complex adaptive systems principles to digital resilience represents a theoretical innovation that captures the emergent nature of both digital risks and organisational responses. By formalising recursive learning, temporal integration, cross-boundary integration, and value amplification as system-level properties, we provide a theoretical basis for understanding how component interactions generate greater resilience value than the sum of isolated capabilities – a phenomenon observed in practice but inadequately theorised in previous literature.

Beyond theoretical contributions, our framework offers significant practical guidance for organisations navigating the complexities of digital transformation. First, the three-component architecture provides organisations with a structured approach to capability development that balances immediate risk mitigation with long-term strategic advantage. By addressing both operational resilience (through ARA) and strategic resilience (through STC), the framework helps organisations avoid the common pitfall of overemphasising one dimension at the expense of the other.

Second, the Digital Resilience Maturity Matrix offers organisations a diagnostic tool to assess their current capabilities and develop targeted improvement strategies. Unlike generic maturity models, the DRMM includes specific measurement parameters for each component at each level, enabling precise capability assessment and development planning. This addresses a critical need identified in our expert validation process, where practitioners frequently cited the lack of clear developmental pathways as a major implementation barrier. Third, our framework's emphasis on integration mechanisms provides practical guidance for addressing the failure to anticipate second-order effects of technological change. The six integration pathways identified in our framework offer organisations concrete mechanisms to ensure that digital resilience capabilities function as an integrated system rather than as isolated functional silos. This integration focus is particularly valuable given that our expert validation process identified siloed organisational structures as a primary impediment to effective digital resilience.

Fourth, the conceptualisation of resilience as a value-creating capability rather than merely a cost centre provides organisations with a more compelling business case for resilience investments. By explicitly linking resilience capabilities to sustainable value creation through the Digital Value Resilience Ratio (DVRR), our framework helps organisations quantify the strategic benefits of resilience beyond mere risk avoidance. This addresses a significant practical challenge identified in our expert validation process, where practitioners frequently cited difficulty in securing executive support for resilience initiatives.

While our research advances theoretical understanding and practical application of digital resilience, several limitations warrant acknowledgement. First, as a primarily conceptual paper, empirical validation of the framework's constructs and relationships remains necessary. Although our expert validation process provided preliminary support for the framework's validity, comprehensive empirical testing across diverse organisational contexts is required to verify its transferability and scalability.

Second, while our framework establishes mathematical relationships between components, these relationships require operational testing to determine their predictive validity. The integration coefficients proposed in our framework represent theoretical constructs that need empirical calibration across different industry contexts and organisational sizes. Future research should focus on developing and validating measurement instruments for these coefficients.

Third, our framework primarily addresses formal organisational capabilities and may underemphasise the role of informal factors such as organisational culture and leadership in resilience development. The interplay between organisational culture and resilience capability formation remains an area for further exploration, particularly how cultural factors might accelerate or impede progression through the Digital Resilience Maturity Matrix.

Fourth, our research design did not specifically address industry-specific variations in digital resilience requirements. While our framework is designed to be adaptable across industries, future research should examine how industry characteristics might necessitate modifications to component specifications or integration

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mechanisms. Industry-specific adaptations of the framework would enhance its practical utility across diverse contexts.

Several promising directions for future research emerge from these limitations. First, longitudinal studies examining resilience capability evolution across maturity stages would provide valuable insights into developmental trajectories and potential acceleration strategies. Such research could identify critical junctures in capability development and provide more nuanced guidance for implementation.

Second, comparative case studies across organisations with different digital maturity levels would help validate and refine the Digital Resilience Maturity Matrix. These studies could identify specific practices and capabilities that enable organisations to progress from one maturity level to the next, providing more granular implementation guidance.

Third, research investigating the relationship between digital resilience capabilities and organisational performance would strengthen the business case for resilience investments. Studies measuring the impact of resilience capabilities on both operational metrics (such as recovery time) and strategic outcomes (such as market share and innovation) would be particularly valuable.

Fourth, exploration of digital resilience in ecosystem contexts represents an important frontier for future research. As organisations increasingly operate within complex digital ecosystems, understanding how resilience capabilities develop and function at the ecosystem level becomes critical. Research examining resilience governance mechanisms across organisational boundaries would address this emerging need.

Conclusions

In an era where digital transformation simultaneously creates unprecedented opportunities and novel vulnerabilities, organisations require integrated approaches that transcend traditional boundaries between strategic management and risk mitigation. The Digital Resilience Capability Framework represents a significant step toward this integration, providing both theoretical advancement and practical guidance for organisations seeking not merely to withstand digital disruptions but to transform them into sustainable competitive advantage.

By reconceptualising digital resilience as an integrated dynamic capability rather than merely a defensive function, our framework challenges organisations to view disruptions as potential catalysts for innovation and strategic renewal. The formal relationships established between anticipatory intelligence, adaptive response, and strategic transformation components provide a structured approach to capability development that balances immediate risk mitigation with long-term strategic advantage.

The framework's emphasis on integration mechanisms and system-level properties acknowledges the complex, emergent nature of both digital risks and organisational responses. This systems perspective addresses critical gaps in current approaches where digital transformation, enterprise resilience, and capability development have evolved in theoretical and practical silos.

As digital technologies continue to transform competitive landscapes and risk profiles, the ability to develop integrated resilience capabilities will increasingly differentiate high-performing organisations from their peers. Our framework provides a foundation for both scholars and practitioners to advance understanding and implementation of these critical capabilities in an increasingly volatile digital world.

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MODELS OF INTERACTION BETWEEN ECONOMIC DEVELOPMENT AND HIGHER EDUCATION *

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Abstract. Modern trends in the country's economic development indicate an increasing influence of the higher education system on the dynamics of economic indicators. The article is devoted to analyzing and modeling the mutual influence of the country's economic development and the higher education system (HES) in the context of achieving sustainable development goals, taking into account differences in external conditions and opportunities. The main attention is paid to identifying the key indicators and patterns that shape the interaction of the national economy and the higher education system, as well as the development of economic and mathematical models that assess such interaction. A conceptual model of the interaction of HES and the level of development of the national economy has been developed, and a set of research hypotheses has been formed. Based on the dynamic analysis of a set of indices, retrospective trends in the development of economic and educational processes have been studied, and portraits of the development of Slovakia and Ukraine have been constructed. Factors reflecting the relationship between the development of the country's economic and educational systems have been identified; the lag structure and fractal nature of their mutual influence have been proven based on model experiments. The following mathematical tools were used: Granger Causality test - to determine the mutual influence and lags of such influence between the indicators of the national economy and HES; Lagged models are used to determine the relationships between factors; VAR models, impulse response, and dispersion analyses are used to study the degree of strategic interaction and assess the mutual influence of economic development and the HES. The obtained results form the basis for developing government approaches to developing, retaining, and attracting talent for long-term sustainable development and enhancing the country's competitiveness.

Keywords: economic development; higher education system; impact; interaction; index; model; Granger test

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1. Introduction

The current stage of civilization's development is characterized by key transformations caused by the large-scale and rapid implementation of technological innovations in all areas of society and the economy. Under these conditions, the landscape of all organizations' activities is changing significantly, requiring a rethinking of their operating paradigms, the establishment of new patterns and rules for organizational management, the

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development of new approaches, methods, and tools for conducting business, and the establishment of new relationships with clients and key stakeholders. Higher education is at the center of these transformations, as it is a necessary condition for creating a more equitable, sustainable, and prosperous future for countries and civilization as a whole. The attractiveness of higher education is steadily increasing. According to UNESCO, the number of students studying in higher education institutions worldwide in 2025 is expected to reach a record 264 million, 25 million more than in 2020, and more than double the 2000 figure. According to OECD data, the number of people with higher education has doubled over the period (2000–2024) and reached 41% of the total population (OECD, n.d.).

As experts from the OECD's Centre for Educational Research and Innovation (CERI) (OECD, 2025) note, the future of higher education is determined by the combination of economic, social, demographic, and technological changes characteristic of the 21st century. Global crises and geopolitical tensions, particularly those triggered by military conflicts, have sparked significant processes of international migration and altered the structure of public spending in many countries. In turn, this has created ambiguous trends in economic growth, social security, democratic participation, and the implementation of technological and environmental innovations, significantly complicating the current and future educational landscape, much like a domino effect. In this context, higher education institutions face the following challenges: learning in an AI-driven world; education on a fragile planet; mind the gaps: inequality, fragmentation, and polarization.

A special place in this list is occupied by the study of the new mutual influence of higher education on the economic development of countries, which corresponds, on the one hand, to the new role of education in strengthening peace and solidarity, and on the other hand, actualizes the need for resistance and resilience of higher education to the challenges of the development of civilization.

2. Literature review

The mutual influence of a country's economic development and higher education is a complex, multifaceted process and is the focus of contemporary scientific and practical research. Economic stability and national development have a direct impact on the quality, accessibility, and attractiveness of higher education, shaping its financial base, student support tools, and opportunities for innovation in the educational process. In turn, the higher education system develops qualified human capital, which facilitates the implementation of the latest scientific research and technological innovations in all types of economic activity, enhances the state's readiness to achieve sustainable development goals, transition to new technological paradigms, and improve societal well-being. It is precisely this interaction that creates a new foundation for a country's competitiveness in the globalized world.

Many scientists (Danyliuk et al., 2021; Ahmadova et al., 2025; Abo-Khalil, 2024; Bucata, Popescu & Tileaga, 2022; Rayevnyeva et al., 2023) believe that the country's stable economic development, supported by long-term investments in educational systems, active development of innovative potential, and gradual modernization of the information infrastructure, creates all the necessary conditions for the transition to an economy based on knowledge and high technology. This approach contributes to strengthening the country's competitiveness in the global market, ensures sustainable growth of human capital, and stimulates the implementation of intelligent digital innovations in various areas of activity of both the country, society, and the higher education system.

Over the past decade, the higher education system has undergone a transformation, with universities becoming increasingly innovative and open to technological changes and the digitalization of socio-economic processes in society. According to scientists (Kraus et al., 2021; Kamath, 2025; Rayevnyeva et al., 2024; Apdillah et al., 2022; Yashchyk et al., 2021; Ketoeva et al., 2025; Xu et al., 2025; Mabungela et al., 2025) at the current stage of digital development, there is a need to rethink the interaction between the higher education system and the labor market. The higher education system must meet the current and future needs of the market, offering programs that graduate specialists with relevant skills and knowledge, while the labor market, in the process of active interaction with universities, should adjust demand and influence the formation of competencies of future specialists, depending on the current and prospective situation in the economy.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/k9463289568

Leading global institutions, such as UNESCO, are defining the new role of higher education. Stefania Giannini, UNESCO's Assistant Director-General for Education (UNESCO, 2025), notes: "The future of higher education is global, digital, and mobile. With millions more people pursuing degrees and alternative credentials, international cooperation on qualification recognition is more critical than ever to support mobility and safeguard trust in qualifications."

Raquel Bernal (2025), President of the University of the Andes, speaking at the World Economic Forum in Davos in 2025, noted that the education system, including higher education, faces specific challenges shaped by global demographic shifts, technological revolutions, and the urgent need to ensure equal access to education. The global higher education system is faced with the need to rethink the essence of education in four key perspectives: increasing flexibility, adaptability, and personalization; significantly increasing the influence of new technologies on the transformation of learning; the transition of the learning process from the “knowledge transfer” model to the “development of skills and thinking” model; increasing the importance of university research in solving global and local problems of societal and national development. All this requires a fundamental rethinking of university activities, the modernization of traditional universal approaches to education based on the priority of individual aspirations and career preferences of students. Achieving these goals requires innovative approaches to implementing modular programs, integrating certificates, transitioning to hybrid learning formats, creating digital platforms, and ensuring universities are prepared for the digitalization of their processes. Reengineering the educational process to develop key competencies of the future (critical thinking and creativity, collaboration and communication, ethical and global awareness), as well as a focus on ensuring equal access to education and its inclusiveness. In this context, the financial and institutional sustainability of education systems and individual universities is crucial and directly depends not only on the initiatives of the universities themselves but also on government financial support.

Kostetskyi, Kutsenko (2021), Alojail and Khan (2023), Alenezi (2023) believe that working with information is becoming one of the most essential skills in the modern world, and digital technologies and products are utilized in almost all sectors of the economy. The authors substantiate that the main areas of digital transformation of educational institutions should be the creation of a digital infrastructure, the formation of a sufficient level of digital skills of teachers, increasing the digital potential of educational institutions, the introduction of a digital component in academic programs, the use of digital educational resources, the development of a digital educational environment, the implementation of digital assessment systems.

The Global Talent Competitiveness Index 2023: What a Difference Ten Years Make What to Expect for the Next Decade (The GTCI report, n.d.) by Fontainebleau (UNESCO, 2025) examines the challenges of transforming future human capital to create new value and enhance talent competitiveness. The research focuses on the idea that competitive talent has a direct impact on a country's economic development. A key task for governments in the 21st century is to develop a set of adequate policies and practices that enable the country to create, attract, and expand the capabilities of its human capital, thereby contributing to productivity and prosperity. In this sense, the Global Talent Competitiveness Index (GTCI) is a crucial component of the talent management ecosystem.

Thus, a two-way interaction exists between a country's economic system and its SES, which is a phenomenon of a new stage in the development of civilization, based on the total digitalization of processes, the active implementation and use of artificial intelligence, the transformation of business and public ecosystems, changing resource priorities, and a focus on the importance of human development. All of this substantiates the relevance of studying the relationship between economic growth and SES, especially given the differences in socioeconomic opportunities and force majeure conditions for the development of individual countries.

3. Research objective and methodology

This article is devoted to analyzing and modeling the mutual influence of a country's economic development and its higher education system (HES) on achieving sustainable development goals, taking into account the varying opportunities conditioned by external conditions.
To achieve the research goal, the following are addressed:

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/k9463289568

1. Studying the characteristics and identifying objective trends in economic and educational processes, taking into account stable and force majeure circumstances, and constructing a portrait of the country's current state;
2. Justifying the dependent and independent influences between indicators of the economic and educational systems and constructing relationship diagrams;
3. Developing a set of models for forecasting the development of the economic system and HES;
4. Defining and modeling the relationship between HES and the country's economic system;
5. Assessing the strategic interaction between economic development and HES.

The solution to the stated problems is based on the proof of the following hypotheses:

1. The development of the country's economic system and higher education system is defined as readiness for the transformations of the 21st century and the implementation of information and communication innovations, as well as the creation of a favorable environment for their competitive development.
2. The interaction between the country's economic system and the higher education system has a lagged, fractal structure.
3. Managing the interaction between the economic and educational systems creates the preconditions for sustainable national development and the creation and attraction of talent to address strategic challenges.

Research methods encompass systems and conceptual approaches, as well as monographic and comparative analysis, index analysis, analysis of structural and logical relationships, econometric modeling, and visualization methods. The conceptual research model is presented in Figure 1.

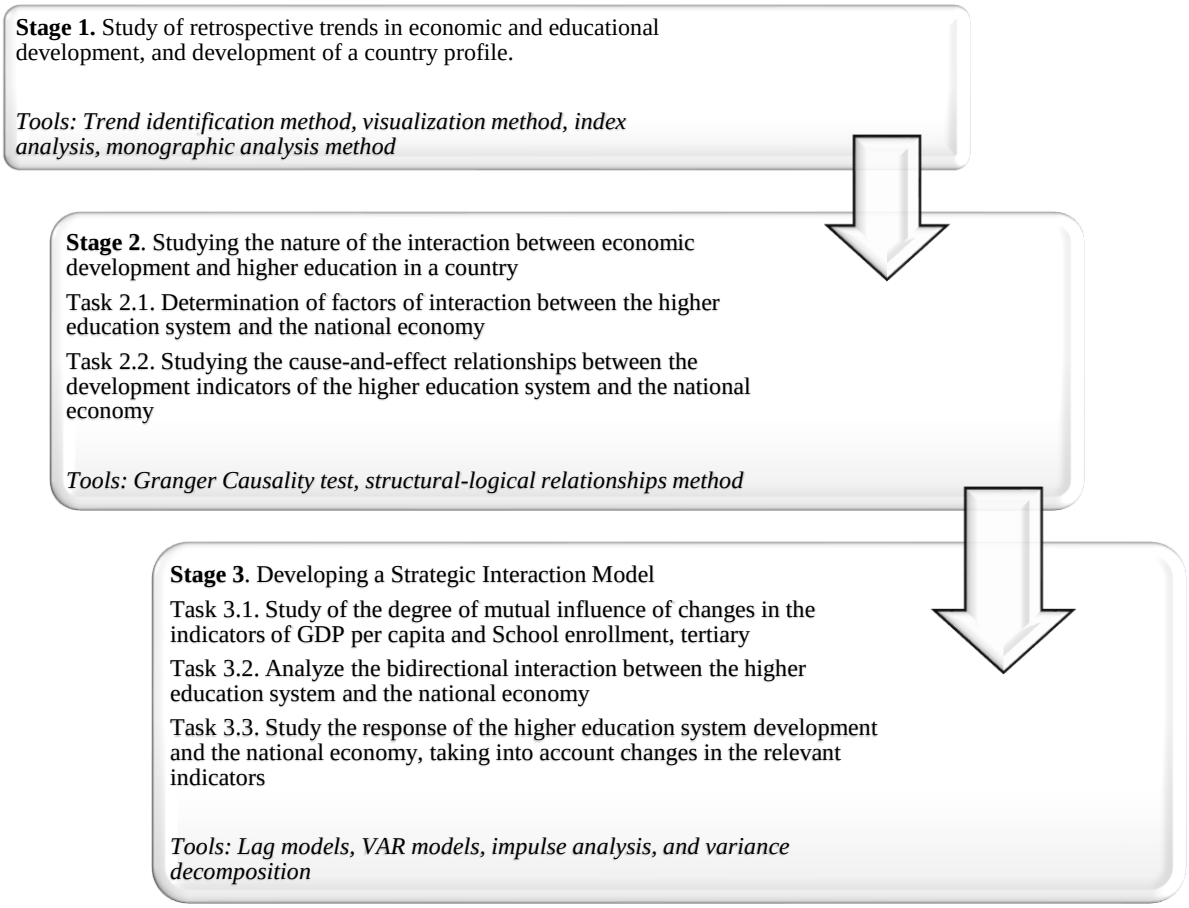


Figure 1. Conceptual research model
Source: compiled by the authors

To solve objective 1, international indices were used, namely: Human Development Index (HDI), Global Talent Competitiveness Index (GTCI), Global Innovation Index (GII), Digital Evolution Index (DEI), Fragile States Index (FSI), Education Index (EI).

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/k9463289568

The Human Development Index (HDI) is a comprehensive measure of human development. It was developed and published in 1990 by the United Nations Development Program in its Human Development Reports and includes three sets of indicators that assess the level of health, education, and economic well-being of a country's citizens (1) (Human Development Report, n.d.):

$$HDI = <Life\ expectancy\ index, Education\ index, GNI\ index> \quad (1)$$

The HDI is calculated using the geometric mean of the three groups of indicators presented above. HDI values range from 0 to 1, allowing for a systematic assessment and ranking of countries based on their quality of life.

The Global Talent Competitiveness Index (GTCI) is a contemporary indicator for evaluating a country's capacity to attract and retain talent (The GTCI report, n.d.). This index was first published in 2013 by INSEAD and the Human Capital Leadership Institute in Singapore. The GTCI model is presented below (2):

$$HDI = < Input, Output> \quad (2)$$

The GTCI is calculated as a simple arithmetic mean of the scores for each subsystem, with values ranging from 0 to 100, indicating that developed, high-income countries occupy the highest positions. The *Input sub-index* includes an assessment of the country's efforts to attract (Enable), select (Attract), develop (Grow) и and retain talented citizens (Retain); the *Output sub-index* assesses vocational and technical skills (VT Skills) and global knowledge skills (GK Skills). VT Skills analyze skills with a technical or vocational basis acquired through vocational or professional training and experience; GK Skills assess the creativity and problem-solving skills needed by knowledge workers in professional, managerial, or executive positions.

The Global Innovation Index (GII) was developed in 2007 by experts from INSEAD (France), with the support of the World Intellectual Property Organization (WIPO) and Cornell University (USA), among other participants. The Global Innovation Index comprises 80 different indicators covering the political situation, education system, infrastructure, and knowledge creation in each country (Global Innovation Index Report, n.d.). All GII indicators are divided into two groups of subindices: the Innovation Input subindex assesses the resources countries invest in innovation; the Innovation Output subindex evaluates the actual results of innovation activities (3).

$$GII = \frac{Sub{-}index\ of\ innovation\ costs + Sub{-}index\ of\ innovation\ results}{2} \quad (3)$$

This index enables us to examine the innovation performance of countries, identifying their strengths and weaknesses, and also to compare their levels of development.

The Digital Evolution Index (DEI) was first calculated in 2014 by Bhaskar Chakravorty, Christopher (Rusty) Tunnard, and Ravi Shankar at the Fletcher School of Law and Diplomacy at Tufts University, USA, in collaboration with Mastercard. The Digital Evolution Index is a tool for assessing the transformation of economies in developed and developing countries from traditional to digital. The DEI is calculated using 184 indicators that reflect the current state and pace of digitalization of a country's economy. These indicators are combined into clusters that reflect 35 aspects of digitalization, which are then grouped into 13 higher-order components and ultimately form four drivers of a country's digital development: supply conditions, demand conditions, the institutional environment, and innovation and change (Digital Evolution Index Report, n.d.) (4):

$$DEI = <0{,}25*Supply + 0{,}25*Demand + 0{,}25*Institutional\ Environment + 0{,}25*Innovation> \quad (4)$$

The results of the country's digital evolution assessment are scaled in the range [0÷100], where the highest score is given to countries with a high level of development of digital technologies, services, and citizen engagement.

The Fragile States Index (FSI) was developed in 2005 by the US-based Foundation for Peace and Foreign Policy magazine. It assesses the government's inability to maintain territorial integrity, as well as the country's demographic, political, and economic situation. The FSI is a crucial tool for not only identifying the challenges facing all states but also determining when these challenges exceed a state's ability to overcome them. The FSI comprises 12 indicators, grouped into four categories: cohesion, economic, political, and sociodemographic (Fragile States Index Report, n.d.) (5).

$$FSI = \sum Cohesion + \sum Economic + \sum Political + \sum Social \quad (5)$$

Each indicator in the group is assessed on a scale of [0÷10], where 10 is the highest level of instability.

The Education Index (EI) is a global index developed by the United Nations Development Program, measuring literacy and education coverage (UNDP, n.d.). The EI is calculated as the adult literacy index and the gross enrollment index and includes key aspects such as education coverage, the quality of educational programs, the accessibility of academic institutions, and the literacy rate of the population (6).

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
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*Education Index = (0,75*Mean Years of Schooling Index) + (0,25*Expected Years of Schooling Index)* (6)

The obtained calculation results are standardized as numerical values on a scale from 0 (minimum) to 1 (maximum).

To solve objectives 2-4, the following mathematical tools were used in the study:

*Granger causality tes*t — this is a statistical test that determines whether one time series helps predict another. There are two stationary time series, X_t and Y_t. Classical Granger tests whether adding lags X_{t-i} to the forecasting model improves the forecasting of Y_t compared to a model using only lags Y_{t-j}. This test uses the hypothesis H_0: lags X do not cause changes in Y, that is, the coefficients $\beta_1=\beta_2=...=\beta_m=0$ in the model (Stiglitz, 1974).

$$Yt = \alpha_0 + \Sigma(\alpha_j\, Y_{t-j}) + \Sigma(\beta_i\, X_{t-i}) + \varepsilon\_t$$

If hypothesis H_0 is rejected, then factor X is the cause of the change in factor Y.

The Granger causality test has the following assumptions: 1) the time series must be stationary; 2) the lag structure must be correctly specified; 3) the model must be linear, and the model residuals must not have autocorrelation.

The limitations of the test are as follows:

The test establishes mathematical causality, whereas there may be no economic meaning in causality; therefore, it is essential to consider economic meanings when testing multiple indicators for causality.

there may be a hidden factor or common driver (spurious causality) that will jointly influence all factors in the aggregate. Therefore, its influence will limit the investigation of the causality of other factors.

The more complex the system, the less appropriate its decomposition into local systems is, particularly when studying the interaction of individual factors in pairs.

VAR models. The model has the following formal form (7)

$$\begin{aligned} X_{1,t}&=a_{10}+a_{11}X_{1,t-1}+...+ a_{1p}X_{1,t-p}+...+ b_{1p}X_{n,t-p}\\ X_{2,t}&=a_{20}+a_{21}X_{1,t-1}+...+ a_{2p}X_{1,t-p}+...+ b_{2p}X_{n,t-p}\\ &\dots\\ X_{n,t}&=a_{n0}+a_{n1}X_{1,t-1}+...+ a_{np}X_{1,t-p}+...+ b_{np}X_{n,t-p} \end{aligned} \quad (7)$$

where n – the number of variables; p – optimal lag of the VAR model.

The VAR model is based on the following assumptions: 1) all variables in the model are endogenous, that is, they act as a result of the influence of other factors in the model system; 2) time series must be stationary or reduced to stationarity; 3) model errors ε_t are uncorrelated with previous values of the regressors; 4) the choice of lags must be mathematically justified (Jeff E. Biddle, 2021).

This class of models offers significant advantages when modeling interactions between systems, namely:

it allows for modeling dynamic relationships between multiple time series;

it does not require pre-definition of exogenous variables, as exogenous variables in turn become endogenous;

it is used for forecasting, impulse response analysis, shock assessment, and variance decomposition, which allows one to determine the influence of certain factors on the outcome factor.

4. Results and recommendations

Stage 1. Study of retrospective trends in economic and educational development, and development of a country profile. The 21st century is a period of globalization and digitalization, the development of new knowledge, change, and large-scale innovative progress, encompassing virtually all aspects of society and national life. This large-scale transformation poses a crucial challenge for the state: it is necessary not only to retain existing talent within the country, creating favorable conditions for their development and activity, but also to actively attract new, highly qualified specialists. All this will strengthen the state's resilience to the challenges of the 21st century through the widespread adoption of innovation, flexibility to adapt to new opportunities in the global economy, trends in scientific and technological progress, and a new understanding of the role of human capital and skilled labor in the country's socioeconomic development.

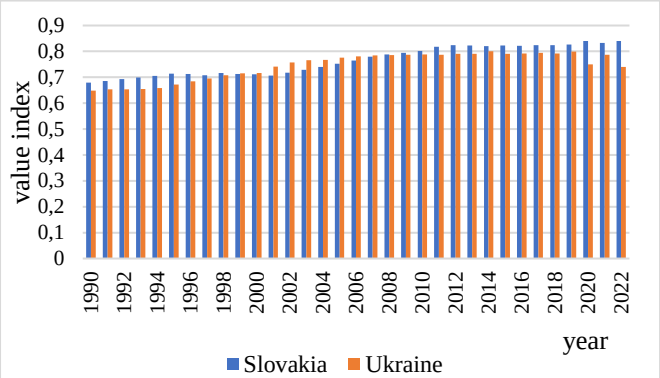
To analyze the created opportunities and the environment for innovative societal development, the study constructed a portrait of the country's development. A set of international indices was used as a toolkit, enabling a systematic assessment of the country's socioeconomic status, education level, security, and capacity to implement various innovations and transition to a new technological paradigm. The results of the analysis will

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2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/k9463289568

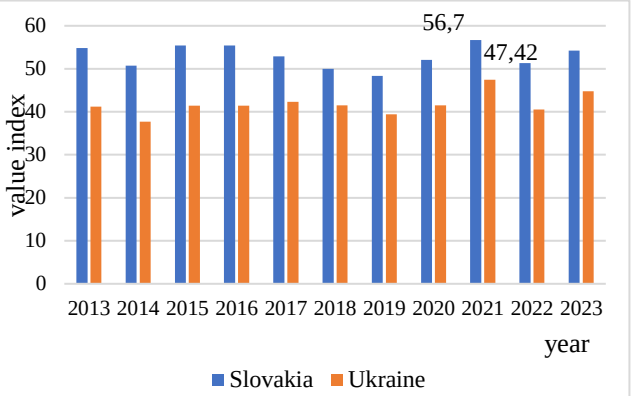
help formulate several areas for further interaction between the country's economy and educational environment to retain human resources under normal and unforeseen development conditions.

Figure 2 presents the Education Index (EI) and the Global Talent Competitiveness Index (GTCI), which provide a comprehensive assessment of the development of the educational system and the degree to which society is realizing its individual potential. These indices help analyze the quality of education provided, professional development, and success in creating conditions for the realization of personal and professional talents, which, in turn, significantly impacts the social and economic development of a region or country as a whole.

The EI is an integrated indicator used to assess educational development in a country or region, allowing the current state of the education system to be measured and the problem areas requiring improvement to be identified. Furthermore, it plays an important role in shaping sustainable development strategies, as high-quality education, including higher education, is the foundation for social, economic, and scientific progress.



a) Education Index



b) Global talent competitiveness index

Figure 2. Dynamics Education Index и Global Talent Competitiveness Index
Source: compiled by authors based on GTCI report and UNDP

Figure 2 shows that for Slovakia and Ukraine, despite differences in their levels of economic development and state operating conditions (Slovakia – normal development conditions; Ukraine – force majeure military conditions), the education index has similarly high values (Ukraine – 0.65–0.8; Slovakia – 0.67–0.84), indicating the presence of an environment stimulating human capital development.

The education index in Ukraine for the period 1990–2022 demonstrates significant changes reflecting the various stages of the country's socio-economic development:
- 1990–2006 – a period of increasing numbers of educated people, indicating the level of accessibility and quality of education, as well as progress in the country's socio-economic development;
- 2007-2018 - a period of stable development despite transformations and challenges, namely the transition from an 11-year to a 12-year education system, which began in 2018 with the introduction of the New Ukrainian School concept, the strengthening of the role of the bachelor's degree as a foundation for higher education following the adoption of the Law on Higher Education in 2014 (Official portal of the Verkhovna Rada of Ukraine, 2014), and the need to optimize the structure of secondary and higher education, despite high levels of higher education enrollment;
- 2019-2022 - a period of development under force majeure conditions, characterized by a large-scale transition to online learning, the introduction of new educational technologies, and approaches to teaching, which became particularly relevant during COVID-19 and Russia's military aggression against Ukraine.

Regarding the development of education in Slovakia, it has demonstrated positive dynamics through reforms aimed at aligning with European standards, including the integration of higher education into the Bologna Process and improvements in the quality of education. Key changes included restructuring the secondary education system, developing public and private education, and emphasizing free higher education at public

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
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universities for all applicants with a sufficient level of Slovak language proficiency. All of this contributed to an increase in the number of educated people in the country.

The dynamics of the Global Talent Competitiveness Index for Slovakia and Ukraine for the period 2013-2023 (Figure 2) show a unidirectional, nonlinear trend, driven by both the countries' strengthened positions on the international stage thanks to improved infrastructure and educational reforms, as well as the challenges they faced, such as the outflow of qualified specialists abroad or insufficient investment in professional development. An analysis of the index values suggests a middle-of-the-road position for these countries in the ranking, as index values for Slovakia fluctuate between 0.48 and 0.57 over the analyzed period, while for Ukraine, they range from 0.38 to 0.45. This demonstrates the need for government intervention: in the Input sub-index for Slovakia and Ukraine, it is about developing talented citizens (Grow); in the Output sub-index, it is about strengthening global knowledge skills for Slovakia; and for Ukraine, it is about strengthening global knowledge skills and vocational and technical skills. The highest index values for the analyzed countries correspond to 2021, the year of economic recovery after the global pandemic (Figure 2).

The Human Development Index (HDI) is an integrated indicator that assesses a country's attractiveness for highly educated people. By assessing a country's situation from three perspectives—long and healthy life, access to knowledge, and a decent standard of living—this indicator allows one to evaluate government efforts to preserve human capital for future economic development. Figure 3 shows the HDI trends for Slovakia and Ukraine.

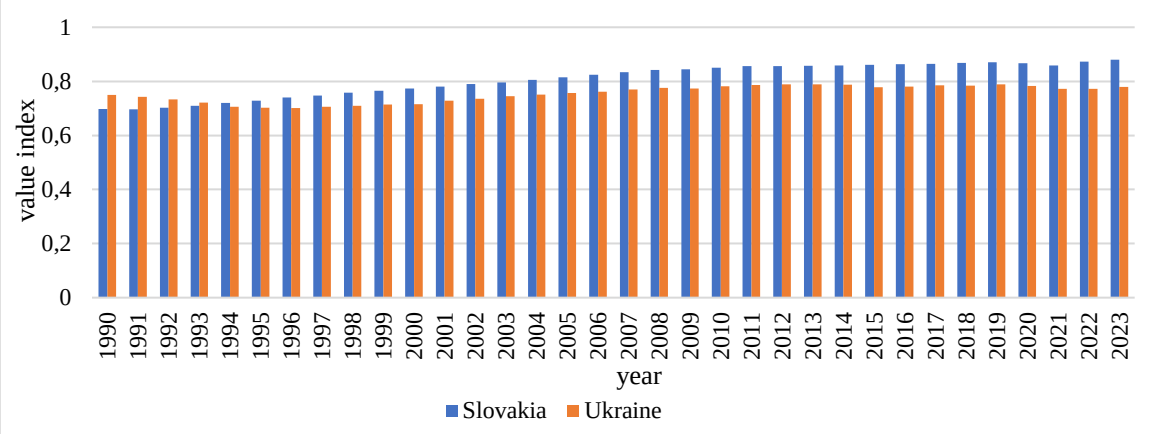


Figure 3. Dynamics Human Development Index by Slovakia and Ukraine
Source: compiled by authors based on Human Development Report

Figure 3 for Ukraine shows that from 2001 to 2014, there was a steady increase in the index, followed by a period of stagnation and a slight decline. Since 2020, the HDI has begun to decline, although this decline was not significant compared to global indicators. Ukraine's HDI dynamics for 1991-2023 can be roughly divided into three periods:
1991-2014 - a period of growth, meaning that during this period, the HDI increased from 0.71 to 0.77, reflecting the country's positive socioeconomic development;
2015-2019 - a period of stagnation, with the average HDI value being 0.78;
From 2020 to the present, the index has declined by 0.2 points due to declining life expectancy, per capita income, rising unemployment, and force majeure events such as COVID-19 and military action.

Although Ukraine still has an index value above the global average, the overall deterioration in the population's quality of life, economic decline, and rising public debt, problems in the real economy, funding constraints in higher education, and, most importantly, a significant loss of life security, make the country unattractive for human capital.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
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An analysis of Slovakia's HDI dynamics showed steady growth over the analyzed period, reflecting progress in improving the quality of life, increasing life expectancy, advancing education levels, and improving economic development. Thus, Slovakia demonstrates a high level of socioeconomic development, which is a positive signal for retaining and attracting talent.

The Digital Evolution Index (DEI) provides a national-level assessment of the current state of development and potential for digital technology adoption. It is an important tool for analyzing a country's competitiveness, identifying its strengths, and identifying areas requiring additional attention to ensure sustainable progress in the digital economy and human capital development. Figure 4 shows the DEI dynamics for Slovakia and Ukraine.

Slovakia's Digital Evolution Index analysis revealed rapid progress in the European Digital Competitiveness Index, improving its position by 18.55 points in 2023 compared to 2008. This reflects the country's commitment to digital transformation, which aligns with its national development strategy to ensure high-speed internet access by 2030 and support the diffusion of artificial intelligence across all sectors of the country.

Despite the force majeure conditions of 2022-2025, the Digital Evolution Index in Ukraine also demonstrates positive changes in the digital transformation process. Index values have increased by 23.43 points over 15 years, reflecting significant potential for further growth in digitalization thanks to digital literacy, access to technology, high-speed internet, and other factors.

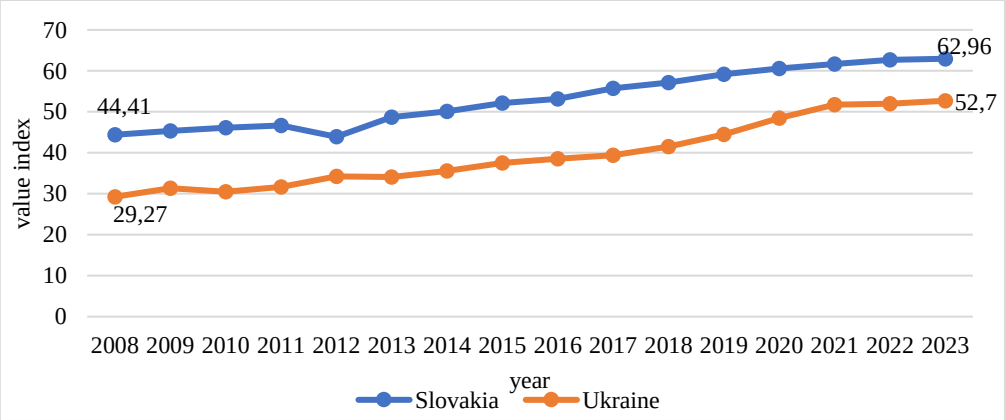
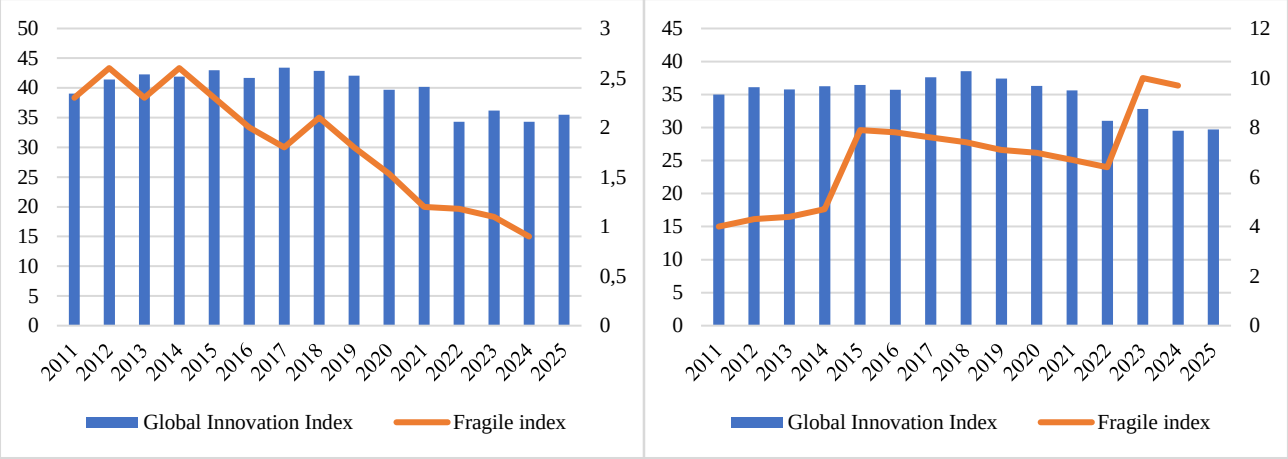


Figure 4. Dynamics Digital Evolution Index by Slovakia and Ukraine
Source: compiled by authors based on Digital Evolution Index Report

The sustainability of modern national development is characterized, on the one hand, by the need and opportunity to implement various innovations, and on the other, by strengthening political, economic, and social institutions. Therefore, the study used the Innovation Development Index and the State Fragility Index, whose dynamics are presented in Figure 5. The Innovation Development Index reflects the level of development and implementation of cutting-edge technologies and the contribution of innovation to economic and social development; the State Fragility Index assesses countries' vulnerability to various internal and external challenges, including political instability, economic difficulties, and social tensions. Both of these metrics serve as essential tools for analyzing state resilience and capacity, providing insight into a country's development dynamics.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/k9463289568



a) Slovakia b) Ukraine

Figure 5. Dynamics Fragile index and Global Innovation Index by Slovakia and Ukraine
Source: compiled by authors based on Fragile States Index Report and Global Innovation Index Report

An analysis of trends in the Innovation Development Index for Slovakia and Ukraine for 2011–2025 revealed similar nonlinear dynamics, with a characteristic decline in index values at the end of the analyzed period (Slovakia – 4.5 points; Ukraine – 5.3 points). The reasons for this decline were insufficient investment in research and development, low levels of technological infrastructure, patent activity, and the effectiveness of knowledge transfer. Focusing government efforts on improving this situation will accelerate the diffusion of innovations into the economy and society, facilitating adaptation to modern development trends.

Ukraine and Slovakia have opposed trends in their Fragile Index. Slovakia has strengthened its development sustainability since 2014 (Figure 5), as evidenced by a sharp 66 percent decline in its index. Ukraine has an opposite, upward trend in its index; over the analyzed period, its value increased 2.4-fold, reaching 9.7 points in 2024. However, since 2015, the country has seen a positive trend toward strengthening the state (a 1.5-point decrease in index values over the period 2015–2022), which was disrupted by Russia's military aggression (an increase in index values over the period 2022–2024 of 3.4 points).

Thus, the analyzed countries must continuously focus on improving their levels of innovative development, the quality of education, and socioeconomic development, which, in turn, will strengthen their competitiveness on the international stage and stimulate long-term growth. The socioeconomic and innovative development level in countries depends on the quality of education. By investing in education, states create the foundation for training qualified personnel and stimulating scientific potential, which, in turn, influences the formation of an innovative economy and increases its competitiveness.

The research that was conducted allowed for the construction of a portrait of the countries' socioeconomic development (Figure 6). Even though Slovakia and Ukraine have different levels of economic growth and are developing under different conditions (Slovakia – evolutionary development conditions; Ukraine – force majeure), their governments are making significant efforts to retain and attract talent as a driver of their future socioeconomic well-being.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/k9463289568

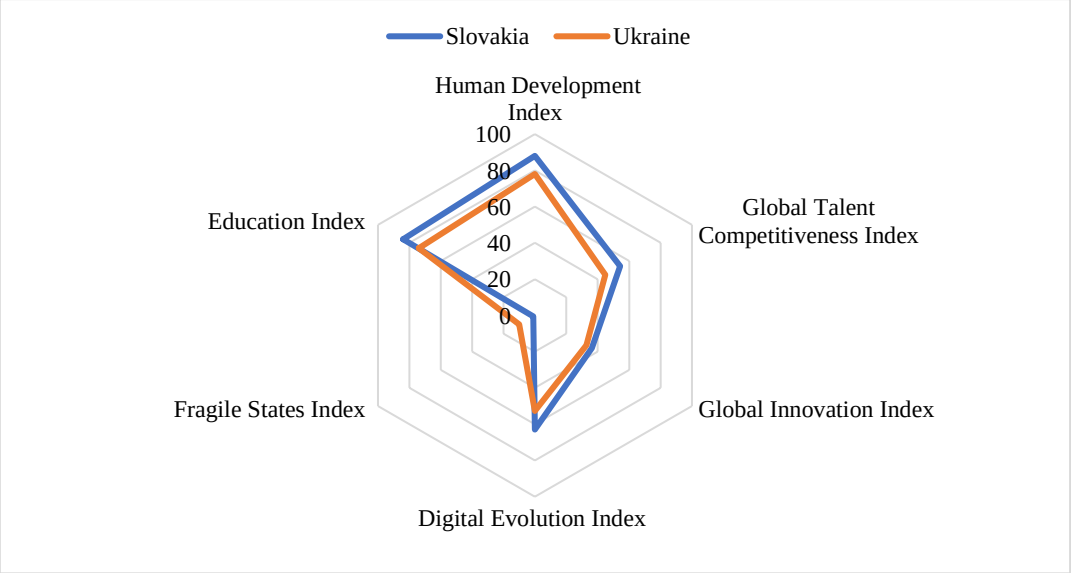


Figure 6. Portrait of the socio-economic development of countries, 2023
Source: compiled by the authors

The resulting portrait reflects the strengths and weaknesses of government efforts to create a favorable socioeconomic environment for development, attracting and retaining talent, which is essential for the new knowledge economy and developing drivers of the country's future competitiveness in global intellectualization and digitalization. Figure 6 shows that Slovakia ranks higher in all analyzed indices in 2023, suggesting the government's ongoing efforts to preserve human capital. Despite facing brutal force majeure circumstances, Ukraine strategically focuses on creating conditions for retaining and attracting talent. However, these efforts are significantly limited by the loss of the economically active population, particularly those with higher education, the decline in economic activity, and the resulting reduction in budget revenue due to Russia's military aggression.

Stage 2. Studying the nature of the interaction between economic development and higher education in a country
Task 2.1. Determination of factors of interaction between the higher education system and the national economy. The study of the content and analysis of the components of the HDI, GTCI, GII, DEI, FSI, and EI indices allowed us to form a list of indicators that will be used to identify the dependent and independent influence between the indicators of the economic and educational systems, and to build a set of structural and logical diagrams of their relationship. This list of indicators includes: 1) School enrollment, tertiary(% gross)- SE; 2) GDP per capita (current US$)- GDP; 3) The level of attractiveness of the higher education system - Inter; 4) Global Talent Competitiveness Index - Talent; 5) The number of students who graduated from higher education institutions - Final; 6) The number of postgraduate students - PhD; 7) The index of expenditure on scientific research to GDP, % - RD_Spending; 8) The Cost of living Index - Cost; 9) The number of researchers - RD_People. The information space for solving the problem is formed by a dynamic series of these indicators for the period 1990-2024; the source of information was the databases GTCI report, World Bank, State Statistics Service of Ukraine, Eurostat database.

Task 2.2. Studying the cause-and-effect relationships between the development indicators of the higher education system and the national economy. The Granger Causality test was chosen as the mathematical tool for solving the problem. To confirm Hypothesis 2 regarding the existence of an interaction between the country's economic system and the SVO, the test was calculated for four lags to determine its lag and fractal structure. The test results for a one-year lag are presented in Table 1.

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2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/k9463289568

Table 1. Research on the causes and consequences of the interaction between the higher education system and the national economy

Null Hypothesis:		F-Statistic	Prob.
FINAL does not Granger Cause COST		6.66647	0.0148
GDP does not Granger Cause COST		12.3528	0.0014
COST does not Granger Cause INTER		4.16705	0.0498
PHD does not Granger Cause COST		4.45516	0.0430
COST does not Granger Cause TALENT		13.3521	0.0009
FINAL does not Granger Cause PHD		19.9955	0.0001
RD_PEOPLE does not Granger Cause FINAL		12.5580	0.0036
FINAL does not Granger Cause SE		8.64248	0.0062
TALENT does not Granger Cause FINAL		3.11361	0.0875
INTER does not Granger Cause GDP		3.71091	0.0633
GDP does not Granger Cause RD_PEOPLE		18.5655	0.0008
SE does not Granger Cause GDP		62.5552	6.E-09
GDP does not Granger Cause SE		4.59182	0.0401
GDP does not Granger Cause TALENT		4.16074	0.0500
RD_SPENDING does not Granger Cause INTER		9.38785	0.0059
SE does not Granger Cause INTER		8.49803	0.0065
INTER does not Granger Cause TALENT		15.3941	0.0005
SE does not Granger Cause PHD		5.15990	0.0302
RD_PEOPLE does not Granger Cause RD_SPENDING		7.32299	0.0180
RD_PEOPLE does not Granger Cause SE		7.86910	0.0149
RD_SPENDING does not Granger Cause SE		5.36992	0.0307
TALENT does not Granger Cause RD_SPENDING		4.19370	0.0533
TALENT does not Granger Cause SE		3.29108	0.0793
RD_SPENDING does not Granger Cause GDP		3.53229	0.0229

Source: compiled by the authors

The calculations presented in Table 1 enabled the construction of a system of dependent and independent influences between the analyzed indicators (Table 2).

Table 2. Granger test results for lag 1

Cause	Effect
The number of students who graduated from higher education	Cost of living
GDP per capita	
The number of postgraduate students	
The Cost of living Index	The level of attractiveness of the higher education system
The index of expenditure on scientific research to GDP	
School enrollment, tertiary	
The Cost of living Index	Global Talent Competitiveness Index
GDP per capita	
The level of attractiveness of the higher education system	
The number of students who graduated from higher education	The number of postgraduate students
School enrollment, tertiary	
Number of researchers	The number of students who graduated from higher education
Global Talent Competitiveness Index	
The level of attractiveness of the higher education system	**GDP per capita**
School enrollment, tertiary	
The index of expenditure on scientific research to GDP	
GDP per capita	**School enrollment, tertiary**
The number of students who graduated from higher education	
Number of researchers	
The index of expenditure on scientific research to GDP	
Global Talent Competitiveness Index	
GDP per capita	Number of researchers
Number of researchers	The index of expenditure on scientific research to GDP
Global Talent Competitiveness Index	

Source: compiled by the authors

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2025 Volume 13 Number 2 (December)
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These Tables 2 allow us to draw the following conclusions:
1. In the short term, a correlation is observed between the GDP per capita and school enrollment (tertiary) indicators. To suggest that, on the one hand, the higher the level of economic development, the more people desire higher education. On the other hand, the more people enroll in universities and, as a result, the proportion of the economically active population with higher education increases, the more GDP per capita increases.
2. Interestingly, the GDP per capita and school enrollment (tertiary) indicators are significantly influenced by the extent to which the state funds scientific research, that is, the state's scientific potential development.
3. With a one-year lag, the standard of living (Cost of Living) depends on the number of students who graduate from universities, economic development, and the number of people who want to pursue further research (the number of postgraduate students).
4. The attractiveness indicator of higher education depends on the Cost of Living, the research investment index, and the School Enrollment (tertiary). This indicates that the more a state invests in R&D and the better the living conditions of the country's population, the more people desire a high level of education.
5. The talent index, with a one-year lag, directly depends on the population's standard of living and economic development, as well as on the attractiveness of the higher education system. In our view, this reflects the creation of opportunities to improve the quality of a country's human capital while improving its socioeconomic development.
6. The number of researchers directly depends on the level of economic development; i.e., the higher the level of economic development, the greater the country's opportunities to stimulate scientific research, which serves as the basis for the country's innovative development.
Thus, the identified structural and logical relationships between the analyzed indicators allowed us to construct an interaction graph (Figure 7).

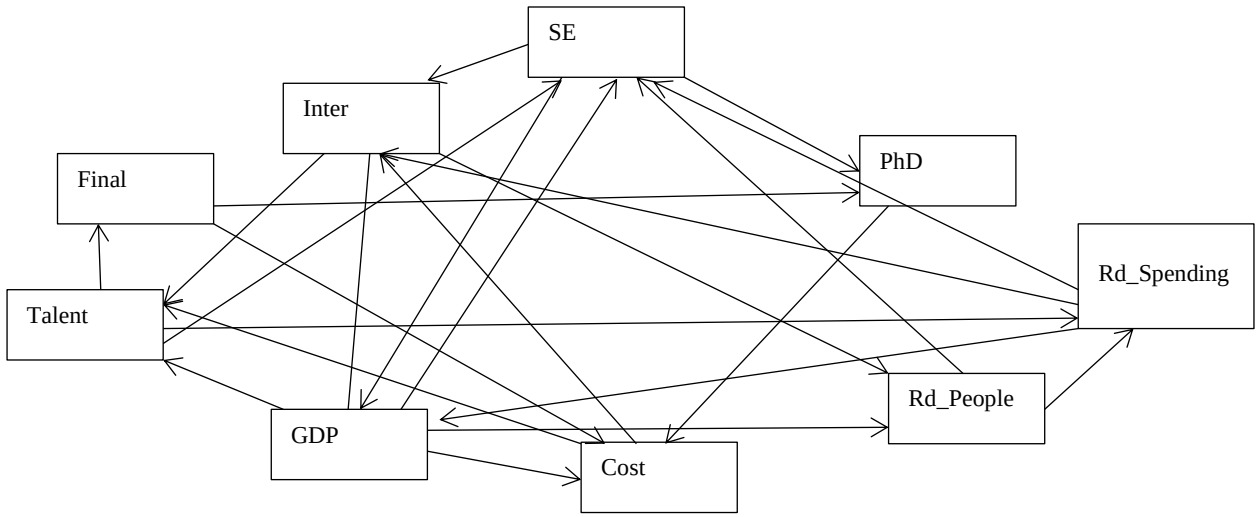


Figure 7. Graph of interaction and connection of indicators with lag 1
Source: compiled by the authors

To prove the stability of the relationships between the analyzed indicators, calculations were carried out for lags 2, 3. Table 3 presents the results of comparing the interaction for lags 1 and 2.
Based on the data in the table, the following general conclusions can be drawn:

1. At a short lag (lag 1), the national economy and the HES have a strong mutual influence, demonstrating the need to stimulate both economic development and the development of the HES to preserve, retain, and attract talent to create competitive advantages for the country's socioeconomic development. With an increasing lag (lag 2), the mutual influence intensifies, deepens, and extends to the scientific sector, increasing the number of researchers and graduate students.

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Table 3. Comparative analysis of lags 1 and 2

Direction of influence	Lag 1 (p-value)	Lag 2 (p-value)	Conclusion
$SE \rightarrow GDP$	6.E-09	1.E-08	A stable and extremely strong connection between higher education institutions and the national economy.
$GDP \rightarrow SE$	0.0401	0.0004	The effect of economic growth, which leads to a more stable connection between the national economy and HES over time.
$PhD \rightarrow GDP$	-	0.0105	The impact of the number of postgraduates on the national economy is manifested no earlier than after two years.
$GDP \rightarrow Rd\_people$	0.0008	0.0014	Stable causality is observed in both lags, which indicates a close connection between the national economy and the number of researchers.
$SE \rightarrow PhD$	0.0302	0.0004	A strengthening of causality is observed, with a lag, the impact of higher education on the number of postgraduates increases.
$Final \rightarrow SE$	0.0062	0.0118	For two lags, a constant, strong effect is observed.
$Rd\_people \rightarrow SE$	0.0149	0.0226	The involvement of researchers increases the educational level of the state, and this connection is constant in the lag structure.
$Rd\_spendin \rightarrow SE$	0.0307	0.0412	A stable dependence is observed.
$Rd\_people \rightarrow Rd\_spending$	0.0180	0.0021	As the lag increases, the effect increases, proving the strong influence of the number of researchers on funding research and development work.
$Rd\_spendin \rightarrow Inter$	0.0059	0.0672	With increasing lag, the effect of investment on HES attractiveness decreases.
$Inter \rightarrow Rd\_people$	-	0.0359	After two years, a new effect appears - the effect of HES attractiveness on the number of researchers.
$Inter \rightarrow Talent$	0.0005	9.E-08	With lag 2, a close two-way relationship is observed between the number of people with higher education and the country's talent level.
$Talent \rightarrow Inter$	-	0.0318	
$GDP \rightarrow Cost$	0.0014	0.0024	A stable direct effect of economic growth on the quality of life of the population.
$Final \rightarrow Cost$	0.0148	0.0488	Although causality is observed, it decreases over time.
$PhD \rightarrow Cost$	0.0430	0.0590	The short-term effect (with lag 1) is more substantial than with lag 2.
$SE \rightarrow Cost$	-	0.0280	The effect that appears over time: education affects the cost of living.
$Cost \rightarrow Talent$	0.0009	0.0009	Absolutely stable relationship over time, i.e., the cost of living strongly affects the talent index.

Source: compiled by the authors

2. Over a one-year planning horizon, relationships in the scientific and educational sphere are more operational—investments in research and development influence the attractiveness of the higher education system, while for two years (lag 2), a structural, transitive causality emerges: educational attractiveness → researchers → expenditures → attractiveness of education;
3. At lag 2, systemic delayed effects are observed, while at lag 1, short-term reactions are characteristic.

These studies allowed us to construct a graph of the interrelationships between the indicators, shown in Figure 8. This figure presents the interactions between the analyzed indicators with different time lags. A key feature of this graph is the relationship between HES (school enrollment, tertiary) and national economic development (GDP per capita). As can be seen, the relationship is bidirectional across all study lags, confirming Hypothesis 1. However, the constructed graph can also be used to formulate public policies and management tactics for various areas of the country's development, as it reflects the cause-and-effect relationships between specific indicators. This, in turn, will help create a favorable environment for talent retention.

Stage 3. Developing a Strategic Interaction Model.

Task 3.1. Study of the degree of mutual influence of changes in the indicators of GDP per capita and School enrollment, tertiary. This study addresses this issue by constructing and analyzing lag models of the relationship

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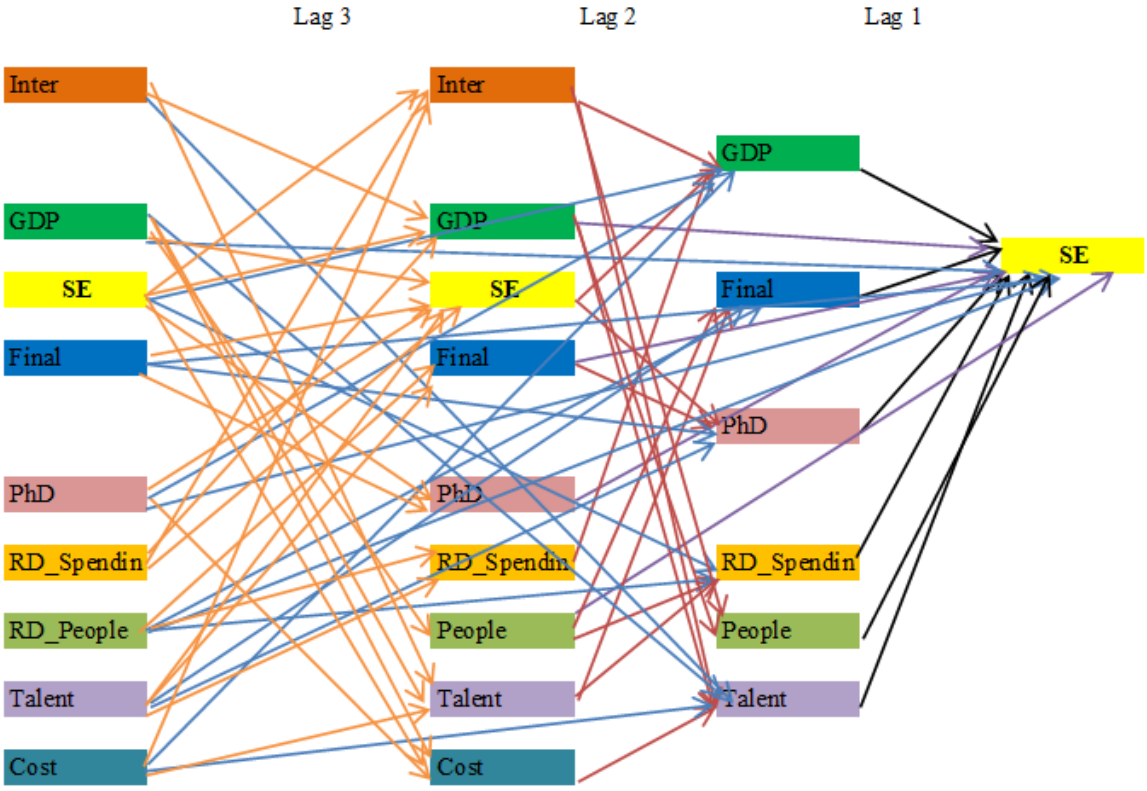


Figure 8. Graph of interactions between factors
Source: compiled by the authors

between the HES and the national economy. The data in Figure 8 and Table 3 were used to determine the lag lengths accurately.

Thus, to predict the dynamics of the School enrolment indicator, tertiary, the following model (8) was developed:

$$SE_t = C + a_1 SE_{t-1} + a_2 Final_{t-1} + a_3 GDP_{t-1} + a_4 GDP_{t-2} + a_5 Rd\_Spending_{t-1} + a_6 Talent_{t-1} + a_7 PhD_{t-1} + a_8 RD\_People_{t-1} \quad (8)$$

The results of calculating the model parameters and assessing its adequacy are presented in Table 4.

Table 4. Calculation of HES research model parameters

Variable	Coefficient	Prob.
SE(-1)	3.298960	0.0007
FINAL(-1)	-0.004447	0.0548
GDP(-1)	0.003864	0.0226
GDP(-2)	-0.007953	0.0137
RD_SPENDING(-1)	28.50564	0.5863
TALENT(-1)	0.397960	0.1530
PHD(-1)	-0.001322	0.2884
RD_PEOPLE(-1)	0.074970	0.1380
C	-230.4204	0.0179
R-squared	0.945422	75.48471

Source: compiled by the authors

As Table 4 shows, the last four factors have little impact on the development of HES and are therefore excluded from the model. Therefore, the calculation of the parameters and adequacy criteria for the modified model is presented in Table 5.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/k9463289568

Table 5. Calculation of parameters of the modified HES research model

Variable	Coefficient	Prob.
FINAL(-1)	0.003206	0.0295
GDP(-1)	0.002311	0.0535
GDP(-2)	-0.006384	0.0122
C	5.939312	0.0373
R-squared	0.794991	

Source: compiled by the authors

Thus, the general model for forecasting HES depending on the factors influencing the national economy has the following form (9):

$$SE_t = 5.94 + 0.885288SE_{t-1} + 0.003206Final_{t-1} + 0.002311GDP_{t-1} - 0.006384GDP_{t-2} \quad (9)$$

The multiple correlation index is high, and this model can be used for further research.

Based on the data in Table 5, the following conclusions can be drawn:

- The high positive correlation between the development of the higher education system and its evolutionary patterns indicates that its development is inertial. This means that systemic changes occur gradually, and the effects of reforms manifest themselves over time.
- An increase in the number of university graduates in the preceding period contributes to the increased attractiveness of higher education among the country's population. A higher education multiplier effect is observed, meaning that the more people obtain higher education, the more young people are eager to enroll in universities.
- The positive impact of GDP per capita on the development of the HES indicates that economic growth increases the accessibility of higher education through improved economic conditions, living standards, and increased funding for the HES. At the same time, the negative impact with a lag of 2 reflects the saturation of educational demand and a shift in the population's focus to the labor market; that is, after an economic recovery, young people are more interested in employment than in further education. The multiple correlation index is high, and this model can be used for further research.

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The general form of the model is as follows (10):

$$GDP_t = C + a_1SE_{t-1} + a_2SE_{t-2} + a_3Inter_{t-1} + a_4PhD_{t-2} + a_5Rd\_Spending_{t-1} + a_6Cost_{t-2} + a_7GDP_{t-1} \quad (10)$$

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/k9463289568

The calculation of the model parameters is presented in Table 6.

Table 6. Calculation of the parameters of the GDP per capita forecasting model

Variable	Coefficient	Std. Error	t-Statistic	Prob.
GDP(-1)	0.476608	0.189181	2.519318	0.0221
SE(-1)	-56.96208	47.13262	-1.208549	0.0243
SE(-2)	47.46352	54.17284	0.876150	0.0302
INTER(-1)	1963.487	801.8640	2.448654	0.0255
RD_SPENDING(-1)	-2719.457	1339.723	-2.029866	0.0883
PHD(-2)	0.110329	0.065975	1.672281	0.1128
COST(-2)	-30.98912	10.93228	-2.834643	0.0114
C	-180.8092	1559.527	-0.115938	0.9091
R-squared	0.900984	Mean dependent var		2793.357

Source: compiled by the authors

Table 5 shows that the parameter for the factor—the number of graduate students—is not statistically significant, so we will conduct a series of experiments with the model to achieve significance for this parameter. The corresponding calculations are presented in Tables 7 and 8.

Table 7. Modification 1 of the GDP per capita forecasting model

Variable	Coefficient	Std. Error	t-Statistic	Prob.
GDP(-1)	0.810524	0.164751	4.919692	0.0000
SE(-1)	64.73369	10.27252	6.301637	0.0000
SE(-2)	-53.06692	25.56788	-2.075530	0.0476
INTER(-1)	879.3275	627.7626	1.400732	0.1727
COST(-2)	-5.635777	8.979780	-0.627607	0.5355
C	-980.8288	685.9523	-1.429879	0.1642
R-squared	0.876711	Mean dependent var		2338.075

Source: compiled by the authors

Table 8. Modification 2 of GDP per capita forecasting models

Variable	Coefficient	Prob.
GDP(-1)	0.824842	0.0000
SE(-1)	66.69067	0.0000
SE(-2)	-60.85191	0.0103
INTER(-1)	868.5090	0.0177
C	-707.4897	0.1879
R-squared	0.886254	

Source: compiled by the authors

Thus, the modified model has the form (11):

$$GDP_t = -707.4897 + 66.691SE_{t-1} - 60.82191SE_{t-2} + 868.5090Inter_{t-1} + 0.821842GDP_{t-1} \quad (11)$$

The obtained results allow us to draw the following conclusions:

1. The economy has high inertia, as confirmed by the high impact of GDP per capita in the previous period.
2. A strong impact of the higher education system with a lag of 1 is observed. This means that expanding access to HES quickly translates into growth in human capital and labor productivity.
3. An adverse effect after two years may indicate labor market saturation and a mismatch between educational competencies and the needs of the national economy.
4. The high attractiveness of HES has positively impacted GDP per capita. The high reputation of education, openness, and the quality of education attract both national and international students, which strengthens the country's intellectual capital, attracts investment into the economy, and improves the competitiveness of the national economy.
5. Sustainable growth of the national economy should be based on the continued support of educational and institutional programs.

Thus, the research confirms Hypothesis 2: the indicators of the higher education system and the national economy have a strong, lagged interaction.

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2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/k9463289568

Task 3.2. Analysis of the bidirectional interaction between the higher education system and the national economy. To address this problem, the study developed a VAR model to determine the strength of the relationship between changes in the higher education system and the national economy. The first step is to test the stationarity of the time series, the results of which are presented in Table 9.

Table 9. Testing the stationarity of time series

	GDP per capita	School enrollment, tertiary
Probability value	0.0954	0.0031

Source: compiled by the authors

The obtained values indicate the analyzed series' stationarity, allowing us to construct a VAR model and calculate its parameters (Table 10).

Table 10. Calculation of VAR model parameters

	SE	GDP
SE(-1)	0.596416	63.45760
SE(-2)	1.197657	-41.39829
GDP(-1)	-0.001662	0.874182
GDP(-2)	-0.012785	-0.118280
C	-20.77729	-822.9796
R-squared	0.820303	0.867610
Akaike information criterion		22.89253

Source: compiled by the authors

To determine the strength of interaction between indicators, was calculated the variance decomposition (Table 11).

Table 11. Results of variance decomposition

	Decomposition SE		Decomposition GDP	
Period	SE	GDP	SE	GDP
1	100.0000	0.000000	30.91897	69.08103
2	99.59231	0.407694	38.10959	61.89041
3	91.15752	8.842475	44.97404	55.02596
4	81.24940	18.75060	78.79375	21.20625
5	73.75307	26.24693	77.57102	22.42898
6	64.58316	35.41684	73.49311	26.50689
7	59.44955	40.55045	64.92224	35.07776
8	54.01785	45.98215	59.48785	40.51215
9	51.01859	48.98141	53.21841	46.78159
10	52.67722	47.32278		

Source: compiled by the authors

The data in Table 11 allow us to draw the following conclusions:
- the impact of GDP per capita on school enrollment, tertiary
1. In the short term (1-2 years), changes in the attractiveness of higher education are explained by intrinsic factors—demographic trends, education policy, etc.—and starting in year 3, the influence of the country's level of economic development on the HES increases;
2. In the medium term (4-6 years), up to 35% of the variation in the HES is explained by changes in the national economy. This means that economic growth gradually translates into a stronger higher education system.
3. In the long term (over 6 years), rising well-being significantly impacts higher education's attractiveness, the creation of new university programs, and student mobility. Thus, approximately 47% of the HES variance is explained by economic development changes.
- The impact of school enrollment and tertiary education on GDP per capita
1. A study of the impact of HES on national economic growth revealed that, starting from the first period, 30.9% of the change in the national economy is explained by changes in HES, indicating that human capital immediately plays a significant role in the development of the national economy.
2. Over a planning horizon of 2-3 years, the impact of HES on the country's GDP increases to 45%, which

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2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/k9463289568

correlates with Lucas's theory of endogenous economic growth, where investment in education is the primary source of economic growth.

3. Over 4-6 years, the impact of HES on the economy reaches its maximum and amounts to 70-78%, indicating the peak of the educational effect on the country's economic development. Although this figure decreases to 50% in subsequent periods, it remains quite significant, demonstrating the ongoing impact of HES on socio-economic development.

Task 3.3. Study the response of the higher education system development and the national economy, taking into account changes in the relevant indicators

To solve this problem, impulse analysis was used based on the obtained VAR models (Figure 9).

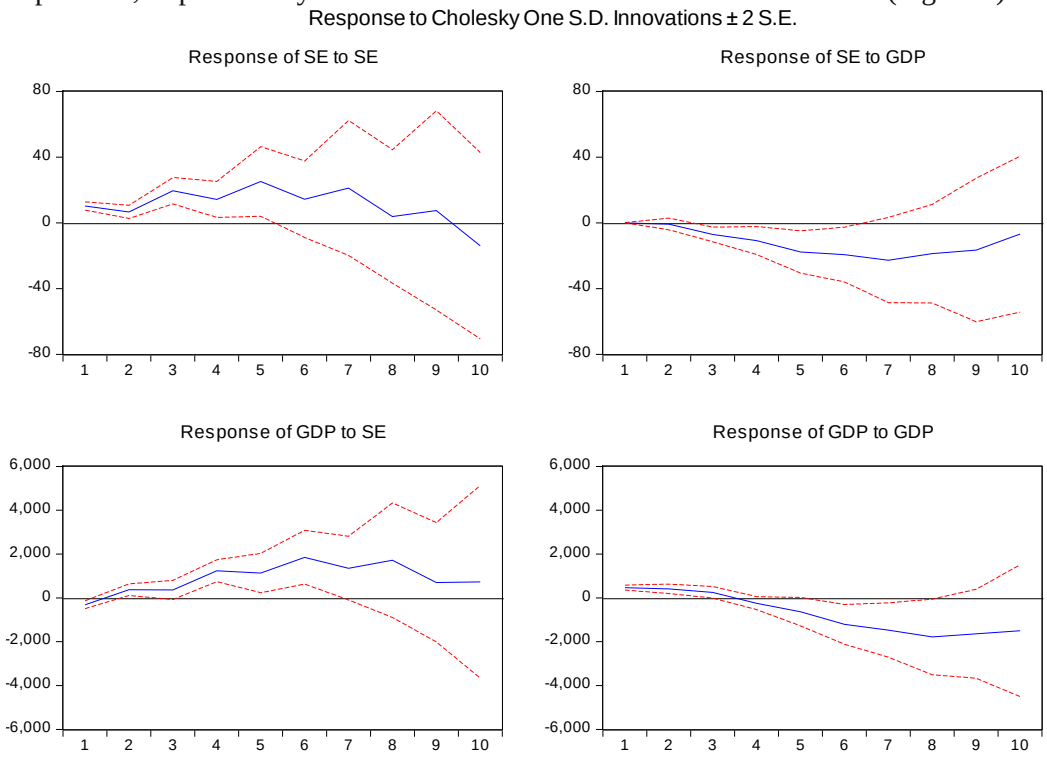


Figure 9. Impulse analysis of the interaction between the higher education system and the national economy
Source: compiled by the authors

An analysis of the results in Figure 9 yielded the following conclusions:

- A positive internal shock to the higher education system leads to growth in the system itself in subsequent periods. The positive response in the first 5 periods indicates the system's inertia. After period 8, this effect diminishes.
- The HES response to a positive shock to economic growth is initially insignificant, and starting in periods 3-4, the curve remains below 0, indicating that GDP stimulates the strengthening of the higher education system only with a lag, rather than immediately.
- During periods 1-6, the GDP response to changes in the HES is positive, promoting continued economic growth; subsequently, the impact stabilizes.
- A positive shock to economic development relative to itself causes a moderate short-term response, which declines to 0 over time, indicating the tendency of this impact to stabilize.

The results that were obtained confirm Hypothesis 3 of the study. Thus, the existence of a relationship and mutual influence between economic development and the development of the HES allows for the creation of a favorable environment for the development of the country's human capital, capable of solving new, complex problems of economic growth, which will ensure the possibility of transition to new technological paradigms and the achievement of sustainable development objectives.

Conclusions

1. An analysis of international indices, such as the Human Development Index (HDI), the Global Talent Competitiveness Index (GTCI), the Global Innovation Index (GII), the Digital Evolution Index (DEI), the Fragile States Index (FSI), and the Education Index (EI), provided a systematic understanding of the country's current status and potential in the context of 21st-century globalization and digitalization. Specifically, the study's findings demonstrate significant progress in education, essential for developing human capital capable of adapting to new technological challenges and stimulating innovative progress in the country. Furthermore, it was determined that, in the context of global transformations, the country must not only retain talent and create favorable conditions for its development but also actively attract new highly qualified personnel. A study of the country's historical trends confirms the need for strategic development of higher education, which will in turn enhance the country's economic growth. The integration of modern technologies, improving the quality of human capital, and active participation in international initiatives will become decisive factors for the country's successful adaptation to global changes and strengthening its position on the world stage.

2. The interaction between the higher education system and the national economy is diverse and time-dependent. The most stable relationships are observed between TER and GDP, research, and talent. These bidirectional relationships indicate a mutually reinforcing effect on the quality of education, the formation of highly educated human capital, and the country's economic development. Short-term effects (lags 1–2) dominate the interaction of indicators such as FINAL → PHD, indicating immediate dynamics of academic progress, while longer lags (3–4) strengthen relationships such as TALENT → FINAL and GDP → INTER, reflecting a delayed systemic impact.

3. Analysis of causal relationships using the Granger test confirms the evolutionary nature of the interaction between education and the economy, where short-term shocks develop into stable long-term dependencies, emphasizing the strategic role of education and innovation in supporting a country's economic development. 4. A model of the national economy's dependence on changes in the HES demonstrates that the higher education system is a key determinant of economic development. Its attractiveness catalyzes the influx of talent, investment, and scientific knowledge, directly stimulating the country's socioeconomic development. Enhancing the attractiveness of the higher education system has both short-term and long-term positive effects on national economic development, underscoring the need for continuous updates to educational programs, the introduction of pedagogical innovations, and new techniques and forms of interaction with students. The higher education system also exhibits a long-term self-reinforcing shock, demonstrating the HES self-organization effect and the constant response of higher education to new challenges in developing national economies and civilization.

Thus, this article analyzed the mutual influence and interaction of a country's strategic and national economic systems. Calculations using the Granger test revealed the existence of close local relationships between factors that also influence the country's economic development. Further research on this topic will aim to develop a comprehensive matrix of strategic interactions among all factors influencing talent development, retention, and attraction to the national economy.

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ROLE OF BLOCKCHAIN TECHNOLOGY IN GREEN BANKING

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Abstract. Climate change, a general deterioration in the global composition of the planet's atmosphere and the growing expectations of the interested parties make a significant difference to the strategic priorities of the banking sector. In this context, green marketing has become a dominant approach to promoting the development of environmentally friendly products. This approach is applied by different businesses, which in turn increases the brand image, transparency of the company or organisation, and consumer confidence. Additionally, blockchain technology, with its own properties of decentralisation, transparency, and stability, offers new opportunities to adopt and implement eco-marketing factors. This article examines the convergence of eco-marketing and blockchain technology in financial institutions, with a focus on commercial banks. A description of how the blockchain methodology can enhance the credibility and consistency of sustainability initiatives, while reducing the risk of non-transparent activities. Based on a comprehensive literature analysis, the study explicitly addresses the key theoretical and empirical aspects of green banking practices, the development of consumer perception, and the potential for mitigating opacity. The results may indicate that, although blockchains can increase confidence in green marketing, their implementation often involves high energy costs, unavoidable integration with existing systems, and potential uncertainty regarding existing regulations. The article presents a conceptual framework for banks to develop sound, technologically based green marketing strategies that align with environmental sustainability and the expectations of interested parties. Research may contribute to increasing attention to digital sustainability and provide theoretical and practical insight into sustainable financial innovation in the banking sector.

Keywords: Green marketing; blockchain technology; green banking; sustainability; consumer confidence; fintech; ESG communication

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1. Introduction

Constant climate change, a general deterioration in the world's ecological environment, and increased expectations from consumers and regulators, like other stakeholders, have compelled financial and credit institutions to reassess their strategies and activities. New green marketing, which promotes products, services, and institutional practices that highlight environmental advantages, is becoming increasingly important in the banking sector, as commercial banks are becoming more willing to demonstrate social responsibility, sustainability, and transparency. At the same time, the technology of blockchains, which has the characteristics of transparency, sufficient stability, and decentralised management, has considerable potential to increase confidence in green finance and marketing initiatives. At the same time, these two challenges - how to link environmental protection and new technologies - merge and open up prospects for the formation of eco-

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marketing and blockchain technologies, thereby making green banking and marketing a crucial area of systematic research.

At the same time, green marketing is an activity that promotes green initiatives, increases the brand value of financial services and improves customer loyalty and corporate image. The aim is to enhance the value of trademarks, goods, and information services, taking into account environmental aspects and promoting social responsibility. These practices include the supply of environmentally friendly products and services, product restructuring to reduce environmental impacts, sustainable production processes, and price-setting strategies that combine environmentally friendly cost reduction factors. This approach encourages the expansion of channels for environmentally friendly activities that mitigate environmental damage. As consumers' awareness of the environmental impact of goods and services continues to increase, credit institutions, like other companies, are adapting their marketing strategies to meet these social needs. In commercial banking, this trend is reflected in green loans, ESG-related financial products, green bonds, sustainable investment opportunities, environmental disclosure and reporting.

The growing need for research is increasingly looking at green marketing. Authors such as Camilleri et al. (2023) claim that sustainability is becoming increasingly important. According to public regulatory legislation and the changing market needs, large companies are adapting their processes to provide goods and services that are either more environmentally friendly or less environmentally damaging. Lievano Pulido and Ramon-Jeronimo (2023) stress that organic marketing is not only a practice of aesthetic or public relations, but also includes planning, implementation, and control, particularly in the areas of pricing, promotion, and distribution, to meet both consumer expectations and institutional objectives of organisations while respecting the limits of ecosystems. At the same time, Alkhatib et al. (2023) emphasise that green marketing encompasses product redesign, sustainable production, and integrated marketing campaigns.

In addition, studies such as Wijekoon et al. (2021), Sani et al. (2024) show that eco-innovation practices over the whole life cycle of goods and services (including end-of-life) have an impact on overall consumer perception. Górska-Warsewicz et al. (2021) explored how new design, packaging, labelling, and communication can help consumers understand environmental initiatives, thereby strengthening trust and customer loyalty. The publication by Ktisti et al. (2022) focuses on genuine green advertising and its role in achieving credibility and influencing consumer decision-making. Research conducted by Majeed et al. (2022) and Mirza et al. (2023) demonstrates that green marketing can provide a competitive advantage when all parties concerned meet sustainability objectives by enhancing the value of all goods or services.

However, the banking sector has fewer practical applications. For example, Pawar & Munuswamy investigate the relationship between green banking practices and green loyalty from the customer's perspective, confirming that green banking practices have a positive impact on the ecological image and ecological confidence. However, the implications for loyalty is less consistent (Pawar & Munuswamy, 2022). Such studies demonstrate that consumers value environmental practices in banking; however, they often overlook how advanced technologies, such as blockchain, can impact or enhance environmental factors.

In the field of financial technology, several research groups have examined how sustainable funding can be ensured through the implementation of emerging technologies. For example, Garg et al. (2021) investigated the perceived benefits of blockchain technology in the banking sector, surveying bank managers and industry experts to identify the key aspects of potential advantages, such as greater security, enhanced transparency, improved efficiency, and increased trust in transactions. Within the framework of sustainable finance, Ren et al. (2023) conducted a systematic review and research agenda that provides a detailed description of how blockchain research interacts with sustainable funding. Their work identifies key directions, including smart green finance contracts, investment traceability, financial inclusion, and governance. Similarly, Mbaidin et al. (2023) summarised the literature on blockchain adoption for sustainable development in the banking sectors of developing countries. Their findings emphasise that regulatory uncertainty, data privacy, and cybersecurity remain the main challenges, while advanced green contracts, risk reduction, and transparency represent emerging opportunities for sustainable banking innovation.

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In general, some directions of literature overlap in part. For example, Ling and Wang (2024) examine the green credit markets in China and demonstrate that blockchain technology can reduce the non-transparent "washing" of green credits and increase the efficiency of green credit systems. Another study, by Baig and Yadegaridehkordi (2024), employing mixed methods (SEM-fsQCA), demonstrates that the use of blockchain strengthens the link between green marketing / green technology practices and sustainability outcomes, acting as an intermediary rather than a mere aid measure. In addition, Mzoughi et al. (2024) examine the effects of risks arising from the intersection of blockchain markets and green finance, revealing the dynamics of environmental impacts in the context of price fluctuations and investment risks.

Despite the abundance of recent studies, several potential shortcomings remain. In particular, although studies have been conducted to assess the benefits or models of technology deployment, there has been less specific analysis of how eco-marketing communications are produced, verified, and disseminated in the commercial banking sector, and how customers react to these information messages. Secondly, in the context of marketing green banks, the potential barriers to blockchain adoption have not been sufficiently addressed, particularly with regard to green energy consumption, other costs, joint integration into existing systems, data privacy, and regulation. Thirdly, research into different regulatory authorities and larger markets for commercial banks is relatively low, and often such research results are concentrated in new emerging markets. Fourth, the impact of adapting green marketing blockchain on final results, such as product confidence, brand perception, customer loyalty, and financial results, is not well understood.

This article, therefore, aims to analyse the characteristics of the eco-marketing of financial products in the banking sector to partially address these gaps, to examine whether blockchain technology is or may be used to support or verify the environmental marketing claims, to examine consumer attitudes to these features and to examine barriers and challenges to trade in such services. The results of this study may provide an additional pillar for banking institutions to develop sound, transparent, and consistent financial marketing strategies that align with general environmental sustainability and customer expectations.

2. Green marketing and blockchain technology literature analysis

2.1. Green marketing and green marketing in the banking sector

Green marketing can be defined as the activity that promotes and advertises environmentally friendly activities, thereby increasing brand value and brand awareness. The implementation of green marketing measures increases customer loyalty and improves the company's image, aiming to enhance the value of the brand, goods, information products, and services related to environmental aspects and social responsibility for the environment. It includes the inclusion of environmentally friendly products, information products and services, as well as practices that promote environmental conservation. This trend is developing rapidly as consumers become more aware of the environmental impact of goods and services. Companies are adjusting their marketing to meet these social needs.

Camilleri et al. (2023) consider sustainability to be an increasingly important topic. According to Camilleri et al. (2023), companies, both large and small, guided by regulatory laws and updated market needs, are adapting their production processes to supply environmentally friendly products to the market. Lievano Pulido and Ramon-Jeronimo (2023) mentioned that green marketing is not only inseparable from an environmentally friendly approach, but also includes planning, implementation, and control. Lievano Pulido and Ramon-Jeronimo (2023) stated that it refers to the pricing, promotion, and distribution of the final product in a way that fulfils three requirements: satisfying consumer needs, achieving the entity's objectives, and achieving both of these objectives in a manner that is respectful and compatible with various ecosystems. Alkhatib et al. (2023) considered green marketing to be a strategy that reduces the environmental impact of a product through product redesign, sustainable production, and integrated marketing campaigns, thereby promoting environmentally friendly products and meeting the demand for sustainable consumption. Moravcikova et al. (2017) stated that green marketing, as part of overall marketing activities, examines both positive and negative aspects, as well as a limited range of environmental issues. Shabbir et al. (2020) considered green marketing to be a management process that involves identifying, anticipating, and satisfying consumer needs and wants. Correia et al. (2023) noted that green marketing is aimed at all consumers, to encourage them to adopt greener habits and appreciate

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2025 Volume 13 Number 2 (December)
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companies' environmentally friendly approaches when selecting their products. Majeed et al. (2022) stated that the primary goal of green marketing is to gain a competitive advantage by strategically positioning products in the minds of customers, and all stakeholders in the value chain must align with green marketing goals, encompassing cooperation and environmental awareness among all stakeholders. Bhardwaj et al. (2023) stated that green marketing has experienced significant growth over the past two decades, and knowledge about green marketing has expanded proportionately across different continents and various topics. Ktisti et al. (2022) noted that green advertising and green marketing have garnered considerable interest from researchers, as consumers and businesses have become increasingly concerned with sustainability issues and green practices in recent years. García-Salirrosas et al. (2022) considered that green marketing is related to consumer purchasing behaviour, is limited and focused on green product purchasing decisions. Górska-Warsewicz et al. (2021) noted that, in this regard, green marketing considers environmental requirements throughout the product design, production, and packaging processes. Skackauskiene et al. (2023) stated that green marketing uses two approaches from an impact perspective. According to Skackauskiene et al. (2023), the first approach focuses on the impact of green marketing on customer purchasing behaviour, while the second one systematises the potential effect on the organisation (with or without customer purchase intention as a moderating/mediating variable). Nabivi (2025) stated that green marketing can increase perceived informativeness because such posts are essentially intended to convey practical insights about sustainability. Vilkaite-Vaitone et al. (2022) mentioned that green marketing was conceived as a combination of organisational activities designed to promote the causes of environmental problems and to propose solutions to neutralise, prevent, and eliminate them. While these ideas remain an integral part of the current green marketing concept, over time the concept has crystallised and enriched considerably. Guerreiro et al. (2021) analysed that as green marketing has become more popular around the world, so has "green education" and consumer scepticism. Wijekoon et al. (2021) considered that eco-innovation involves sustainable environmental practices at every stage of the formation of goods and services. Chen et al. (2015) stated that as green movements gain momentum, consumers will eventually change their purchasing behaviour and become more receptive to green products. Lopes et al. (2023) analysed that combating green manipulation and promoting a sustainable economy is a multifaceted task that is best approached through a set of coherent and interrelated actions. First and foremost, education is at the heart of this process. The first step is to organise educational campaigns to inform the public about what green manipulation is and how to recognise it.

Summarising, it can be stated that green marketing can increase perceived informativeness, as such posts are essentially intended to convey practical insights about sustainability, aimed at promoting awareness of environmental problems and offering solutions to neutralise, prevent, and eliminate them, associated with environmentally conscious consumption.

2.2. Blockchain technology

The essence of blockchain technology is innovative data storage and transmission technology, the essence of which is decentralisation and data immutability. Unlike conventional databases, the blockchain structure allows information to be stored in blocks that are chronologically connected one after the other in a chain. Due to this property, it is practically impossible to change or falsify information, which is why the blockchain is characterised by greater reliability and security.

The blockchain is associated with a decentralised system - this means that there is no single central controller or server. Instead, data is distributed among network participants located worldwide. Each block of the blockchain contains a certain amount of information, such as transaction records, and is linked to the previous block using a unique cryptographic key (hash). A new block can only be added when network participants (through a process called consensus) confirm that all data is accurate and correct. The features of blockchain technology are presented in Table 1.

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2025 Volume 13 Number 2 (December)
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Table 1. The features of blockchain technology

Author	The features of blockchain technology
Habib et al. (2022)	Blockchain is a particularly promising and revolutionary technology because it helps reduce security risks, eliminate fraud, and achieve such transparency.
Tran et al. (2023)	Decentralisation, immutability, transparency, security, efficiency, traceability, and programmability are the features that make blockchain so attractive**.**
Thanasi-Boçe et al. (2025)	Blockchain technology is increasingly recognised as a transformative digital infrastructure that drives environmental, economic, and social sustainability. Still, academic research on its sustainability potential remains fragmented, with limited integration of theoretical models, sector-specific applications, and systemic-level impacts.
Masa'deh et al. (2024)	A distributed database that records all digital events between participants in a decentralised manner.
Baashar et al. (2021).	Decentralised network management is another feature of blockchain in decentralised governance.
Koptyra et al. (2021)	Blockchain is a breakthrough technology used to create distributed databases. Data is stored in the form of a chain that gradually grows, and the stored information is immutable.
Khanfar et al. (2021)	Blockchain technology is a decentralised and distributed data structure. Data is shared in a peer-to-peer network, with open access. Transactions should be certified, verified, and approved by members of the network community.
Johar et al. (2021).	Blockchain provides decentralised, transparent, and secure systems. It is a distributed ledger technology that maintains a ledger of transactions and protects it with cryptography. Transactions are recorded in blocks, and these blocks are linked together through hashing algorithms.
Mohammed et al. (2024)	The existing literature on blockchain technology for business is highly fragmented, making it challenging to fully understand its potential for business applications.
Kitsantas (2022)	BT is the most popular decentralised digital currency. It has been proven to be a viable solution for building trust in a trustless ecosystem that lacks a central authority for financial transactions, such as banks and financial institutions.
Capece & Lorenzi (2020).	Blockchain technology enables the secure and continuous creation and maintenance of large, distributed databases, primarily designed to manage transactions (data record operations).
Soltani et al. (2022)	This technology has created a new space for various applications by providing a distributed platform along with encryption algorithms. Initially, this type of technology was used to create a financial transaction platform, with the primary goal of developing a system that could prevent double-spending.

Rahman et al. (2024) stated that the use of blockchain technology is not limited to the banking sector and encompasses various other industries such as asset management, tourism, and traceability systems. The integration of blockchain technology into the tourism sector is gradually materialising through the implementation of innovative business models.

To summarise the opinion of scientists, it can be stated that blockchain is an up-and-coming and revolutionary technology, as it helps reduce security risks, eliminate fraud and achieve such transparency, is recognised as a transformative digital infrastructure that promotes environmental, economic and social sustainability, but academic research on its sustainability potential remains fragmented, with limited integration of theoretical models, sector-specific applications and systemic-level impacts.

3. Research methodology

The article employs a methodological approach that combines scientific literature and case analysis. Analysing scientific literature helps to assess how thoroughly the chosen topic has been researched and how many articles have been published on this topic. Maslauskaitė (2008) states that when conducting a scientific literature analysis, one must be familiar with the significant sources of scientific information necessary for analysing the problem. Not all selected sources of information may be directly helpful in analysing the problem writing style. Chapman (2021) mentioned that qualitative literature analysis must reflect complex intellectual work – systematising the similarities and differences of the analysed sources, emphasising contradictions between different authors' positions and their problematic nature, evaluating the methodologies and results of previously conducted research, applying concepts and empirical tools, and commenting on the connections between different parts of the written work being prepared.

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Case studies are a popular research method in many fields, including business. A case study involves an in-depth analysis and examination of a specific subject. It can reveal insights into problem-solving techniques or provide evidence to support the effectiveness of a particular product or service. Once you have chosen an appropriate case study topic, it is essential to conduct preliminary research. This step helps you gain a better understanding of the topic and ensures that you have all the relevant information.

4. Case studies

***Danske Bank green marketing*.** Danske Bank has set three main priorities in its sustainability agenda: climate change, nature and biodiversity, and human rights and social impact. These priorities are interrelated and reflect the main challenges that Danske Bank aims to address through its sustainability efforts, which are divided into three priority areas: supporting customers in their transition to sustainability, ensuring a strong and resilient bank, and managing societal impacts. Danske Bank has set specific emission reduction targets for its various business areas. (Danske Bank, 2025a, 2025b).

Bank of Jiangsu green marketing. The BoJ's commitment to sustainable development focuses on enhancing human well-being, with a particular emphasis on financing for well-being. The bank integrates sustainability into its operations through a comprehensive management framework, with green financing as one of its key pillars. This approach ensures that the BoJ is aligned with global sustainability goals. The BoJ benchmarks its practices against global standards and engages with the PRB community to learn about good practices. The BoJ has established a green finance support framework to integrate environmental performance into its operations. (Bank of Jiangsu**,** 2025).

The Bank of Lithuania initiated the project "LBChain", which is the first blockchain technology platform service for the financial sector. This project aims to combine technological and regulatory expertise and help the financial and FinTech sectors create innovative services, research new technologies, and apply them in practice. The project provided an opportunity for both Lithuanian and international financial companies and startups to experiment in a safe, innovation-friendly environment. The aim was to promote innovation, deepen knowledge about blockchain technologies and strengthen the competitiveness of the sector (Inovacijų agentūra, 2025).

5. Discussion

Lymperopoulos et al. (2012) reveal specific ideas that can be implemented, such as supporting environmental projects, educating customers and employees to be more environmentally conscious, and participating in relevant events. Lima et al. (2025) examine the following question: Does green marketing influence customer loyalty perceptions, brand associations, perceived quality and brand equity in Brazilian banks? According to Lima et al. (2025), green marketing emerges as a strategic approach that promotes sustainable practices, balancing consumer needs with environmental protection. This approach has been driven by growing ecological awareness and the need to align organisational activities with the principles of sustainable development. Nevertheless, in this context, aspects such as brand equity, quality perceptions and value perceptions are strongly influenced by green marketing strategies. As stated by Lima et al. (2025), brand personality, which reflects the values of the organisation, plays a crucial role in strengthening relationships with consumers, shaping their behaviour and influencing purchase intentions. In the banking sector, sustainable practices can increase customer loyalty, brand recognition, quality perceptions and perceived value, as customers view green products as higher-quality alternatives that meet their environmental concerns.

Sharma (2023) summarises the literature on four concepts – green brand image, green brand value, green brand trust, and green purchase intention – into a single framework, develops five hypotheses, and empirically validates them using structural equation modelling in the Indian banking sector, thereby filling a significant research gap. Sharma (2023) reveals a positive relationship between the four concepts, with green trust partially mediating the relationship between green brand image and green brand value. Sharma's (2023) study has theoretical, managerial, and social implications and will be helpful for researchers, policymakers, and stakeholders worldwide in developing green banking strategies for a resource-efficient future.

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2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/s5967972526

Conclusions

The impact of green marketing is related to compliance with legal requirements on environmental issues, improving the brand image in the market and among the general public, and better control of the production of polluting substances to reduce negative environmental impacts.

An analysis of the case study presented in the article and a literature review accompanying it indicate that the combination of green marketing and blockchain technology is a relatively viable approach for banks to increase confidence and transparency among market players while pursuing overall sustainability objectives. Danske Bank and Bank of Jiangsu illustrate how key banks adopt multi-dimensional sustainability agendas, including environmental, social, and governance aspects in their strategic priorities. Danske Bank's focus on climate change, nature and biodiversity, human rights and/or social impact, as well as overall objectives for reducing emissions and efforts to support customer attraction indicate that green marketing is not only a means of business marketing communication but also an integral part of business strategy and business planning (Danske Bank, 2022, 2024; Danske Bank, 2025a, 2025b). The commercial bank combines various loan and investment portfolios with set targets, offering green loans, sustainable financing, and new investment products tailored to sustainability priorities (Danske Bank, 2024b; Danske Bank, 2023). In the meantime, the other Bank of Jiangsu incorporates sustainability into its management system, making green financing the primary pillar of its banking activities and adopting established standards, such as balancing principles and the principles of responsible banking (Bank of Jiangsu, 2023; JSB China, n.d.). At the same time, these cases demonstrate how banks can implement green marketing in alignment with holistic ESG strategies, integrating the supply of their services and products, portfolio management, and stakeholder engagement.

Thus, based on the studies mentioned and the literature examined, several conclusions can be drawn. Firstly, eco-marketing in banking has undergone a fundamental shift from symbolic signs to more specific actions, such as green financing, setting emission reduction targets, incorporating environmental criteria into risk assessment, and aligning investment portfolios with scientifically sound objectives. Therefore, these are key steps towards making the marketing in question generally meaningful and not just used for advertising. Secondly, consumer confidence is crucial: consumers respond positively when green marketing is based on measurable, verifiable actions and accountability for activities. Without authenticity, banks risk claims of greenwashing, which can erode brand integrity, trust, and loyalty. The literature reviewed (e.g., Lima et al., 2025; Green Banking and customer loyalty studies) shows that the image of the brand, its perceived quality and value depend largely on how green marketing of financial products is implemented.

Third, blockchain technology has the potential to strengthen green marketing by providing immutable verification, traceability, and transparency of sustainability claims. While blockchain is less visible in many of the case studies you cited, and more visible in literature outside of the banking cases, its capacity to reduce information asymmetry, enable verifiable tracking of emissions or sustainability outcomes, and enhance governance practices is substantial. However, this potential is conditioned by regulatory environments, technological maturity, cost, energy efficiency, and how well stakeholders (including customers) understand and trust the blockchain-enabled claims.

Fourth, substantial challenges remain. Among them are trade-offs associated with blockchain (e.g. energy consumption, scalability, cost), variation in regulatory and reporting standards across jurisdictions, internal capacities (technical, managerial) to deploy both green marketing and blockchain technologies effectively, and a gap in empirical research assessing the impact of combining green marketing + blockchain on customer outcomes like loyalty, trust, and willingness to pay for green financial products.

Ultimately, to maximise the benefits, a framework for banking sector features of green marketing should include: (a) clearly defined sustainability priorities (e.g. emissions, biodiversity, human rights), (b) quantifiable and science-aligned targets, (c) transparency of progress and metrics, (d) verification mechanisms (potentially blockchain or other trust-enhancing technologies), (e) communication strategies that educate and engage customers, (f) organisational structures that embed sustainability into lending, investment, risk management, and product development.

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For future research, longitudinal studies are needed to track how green marketing efforts backed by blockchain evolve in real banking institutions; comparative studies across different regulatory jurisdictions; and studies that measure the quantitative effect on consumer behaviour, financial performance, and risk exposure. Moreover, research should focus on how the energy efficiency of blockchain solutions is managed to avoid undermining the environmental benefits with high indirect costs.

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INTENTION TO PAY FOR ENVIRONMENTAL SERVICES: A CASE STUDY OF TOURISM ENTERPRISES IN THE MEKONG DELTA, VIETNAM

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Abstract. The study aims to analyze the factors influencing the intention of tourism enterprises in the Mekong Delta to pay for environmental services. The partial least squares structural equation modeling (PLS-SEM) was used to test the research hypotheses using data collected from 221 tourism enterprises in the Mekong Delta. The analysis conducted using SmartPLS 4.0 reveals that factors such as attitudes, subjective norms, perceived behavioral control, environmental concern, perceived green consumption, expectation of a good life, and government policies have a significant positive impact on the intention to pay for environmental services among tourism enterprises in the Mekong Delta. Based on these findings, the study provides implications and recommendations to encourage the intention to pay for environmental services among tourism enterprises in emerging economies like Vietnam. This study provides valuable insights for emerging economies to promote sustainable tourism development through environmental services.

Keywords: intention; Mekong Delta; payment for environmental services; PLS-SEM; tourism enterprise

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1. Introduction

In recent decades, tourism has become a major industry worldwide, significantly impacting global economic growth. According to data from over 180 countries and territories collected by the International Labour Organization, tourism and travel contributed 10.9 trillion USD, representing 10 percent of global GDP, and generated 357 million jobs, or 10 percent of total global employment (UNWTO, 2024). Today, tourism remains one of the most dynamic and fastest-growing sectors of the economy. The tourism industry serves as a key driver for job creation and the development of local economies, cultures, and products, especially by directly and indirectly supporting employment for women and youth, and encouraging growth through micro, small, and medium-sized enterprises. However, despite these benefits, tourism enterprises are among the leading contributors to environmental impact, as they influence the sustainability of destinations through the consumption of natural resources. Hundreds of environmental service payment programs have been implemented worldwide, with annual payments reaching up to 36 billion USD (Salzman et al., 2018). In many countries, the payment for ecosystem services is often introduced in the tourism sector by international organizations or voluntary enterprises. This payment generally depends on site-specific negotiations or entrance fees. Under the payment for ecosystem services framework, recipients such as households, communities, or landowners involved in tourism receive compensation for managing and protecting landscapes and natural resources that are highly valuable for tourism. In Vietnam, according to Article 61 of the Law on Forestry 2017,

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one of the five environmental services subject to payment for forest environmental services is "Protection of natural landscape and conservation of biodiversity of ecosystems for tourism services." Additionally, the law states that organizations and individuals involved in ecotourism, entertainment, and related enterprises must pay for services to protect and maintain the natural landscape's beauty and preserve the biodiversity of forest ecosystems. Furthermore, according to Article 59 of Decree 156, the payment level for forest environment services applicable to these parties is at least 1 percent of the total revenue collected during the period.

The Mekong Delta covers about 40,500 km^2 and is a key economic, ecological, and cultural region of Vietnam. It boasts a diverse ecosystem that includes mangroves, swamps, lowlands, intertwined rivers and canals, and extensive coastlines. Additionally, the Mekong Delta is a high-biodiversity area and is home to many communities with rich cultural identities, offering great potential for biotourism, community tourism, and experiential tourism. In recent years, many tourism enterprises in the Mekong Delta have focused on harnessing local values to generate high revenue and profits. However, the payment for forest environment services in tourism in Vietnam overall, and in the Mekong Delta specifically, remains very limited. Due to the variety of stakeholders, types of operations, and the complex relationships between suppliers, brokers, and buyers, as well as revenue overlaps in the tourism sector.

Recently, research by Do et al. (2023) has combined research and quantitative methods through in-depth interviews, group discussions, and interviews with households that are forest owners to evaluate the implementation of the policy on payment for forest environmental services in Bac Yen district, Son La province. The study results show that the policy has significantly impacted local people's awareness and activities, improved the forest environment, and contributed to enhancing the village's public works in the study site. Lately, research by Nguyen et al. (2023) used the PLS-SEM model to analyze the willingness to pay for mangrove environmental services in Phu Long commune, Cat Ba district, Hai Phong City, influenced by factors such as subjective norms, perceived behavioral control, and mangrove-related knowledge. Nevertheless, previous studies have examined the topic of environmental service payments in the Mekong Delta, a region with a diverse ecosystem and significant pressure from tourism development and climate change; however, they have not thoroughly studied tourism enterprises as direct beneficiaries of the environment. More importantly, this article provides the first empirical evidence on the intention of tourism enterprises to pay for environmental services, a key group of financial contributors to the environmental issues of destinations. Therefore, this study aims to fill the research gap by examining the intention to pay for environmental services among tourism enterprises in the Mekong Delta using a behavioral quantitative model.

The article is organized into six sections. Section 1 is the introduction. Section 2 covers the literature review, analytical framework, and research hypotheses. Section 3 describes the research methods. Section 4 presents research results. Section 5 discusses the findings and implications. Finally, Section 6 provides the conclusion and notes some limitations of the study.

2. Literature review and hypothesis development

2.1. Related concepts

Appearing in the 1990s, paying for environmental services has brought many economic benefits to humanity but also caused direct negative impacts on the environment. According to Harper et al. (2025), environmental service payment is any compensation for services, efforts, or any maintenance and improvement of environmental services. Such compensation can be in the form of direct cash or in-kind payments. It includes five main aspects: voluntary transactions, a well-defined environmental service, at least one buyer of the service, at least one seller of the service, and it must be conditional (the buyer only pays when the provider guarantees that the service will be continuously delivered). This view divides payment for environmental services into four types:

- Payment for carbon sequestration and storage services associated with buying and selling carbon credits;
- Paying for biodiversity conservation services, such as conservation donors paying local people to request the cancellation or restoration of an area to create a natural biodiversity corridor;

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- Payment for watershed forest protection services, for example, downstream water users pay upstream farmers through land use activities that reduce deforestation, land erosion, and flood risks, and so on;
- Paying for services that preserve scenic beauty, like a tour operator compensating local communities not to hunt in a forest used for wildlife tourism.

Payment for environmental services is an economic tool used by beneficiaries of ecosystem services to compensate those who participate in maintaining, protecting, and developing the functions of that ecosystem (Chehabeddine et al., 2023; Moba & Piluso, 2024, Le et al., 2024). This perspective is similar to Wunder (2005) and Hamarneh et al. (2024), which considers it an economic mechanism that encourages and benefits communities providing environmental services to promote sustainable financial resources for resource conservation and biodiversity. According to Nguyen et al. (2023), payment for environmental services is a commitment to participate in a contract voluntarily and with legal binding. With this contract, one or more buyers pay for the specified ecosystem services by providing cash or other support to one or more sellers. The seller is responsible for maintaining a certain type of land use for a designated period to produce the agreed-upon ecosystem services. In summary, payment for environmental services is compensation for providing ecological goods and benefits. It can take many forms, such as cash, in-kind support, tax exemption, or the right to use specific resources. A seller is someone willing or compelled to produce environmental goods and services, while a buyer is someone willing or obligated to pay for the benefits they receive from these goods and services.

2.2. Analytical framework

This study investigates the willingness to pay for environmental services and the behavioral intentions of tourism business owners in the Mekong Delta. Therefore, the theory of planned behavior (TPB) model is used to develop the analytical framework. According to TPB, an individual's intention is the basis for performing the actual action. Intention consists of three factors: attitudes, subjective norms, and perceived behavioral control. Currently, most studies tend to expand the TPB model by proposing additional factors and further examining the relationships between them and human behavioral intentions toward environmental products or services (Huang & Ge, 2019; Yue et al., 2020). For this study, we adopted four factors: environmental concerns, perceived green consumption, expectation of the good life, and government policies. The analysis framework is shown in Figure 1 below.

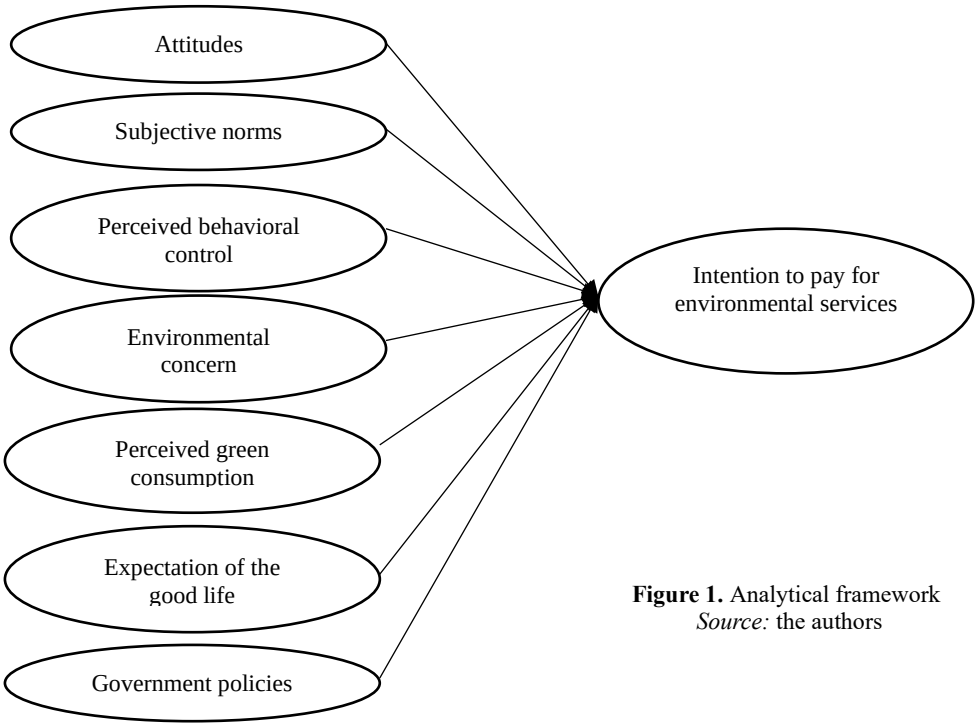


Figure 1. Analytical framework
Source: the authors

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/p3395468557

2.3. Research hypotheses

Attitude refers to the degree of positive or negative evaluation an individual has toward performing a behavior. It is formed from the person's beliefs about the consequences of performing a specific behavior or the outcomes of that behavior (Ajzen, 1991). According to Nguyen and Uong (2024), attitude is the action of what consumers like and dislike, whereby an individual's concern for the environment comes from their perceptions and the level of awareness that they are an essential part of the natural environment. Therefore, the intention of the tourism enterprise to pay for environmental services depends on the attitude of the manager or business owner. Based on the above arguments, the proposed research hypothesis is as follows:

H1: Attitudes positively influence the intentions to pay for environmental services in tourism enterprises.

Subjective norms relate to social pressure that motivates individuals to perform behaviors. They originate from the expectations of family, friends, and colleagues that the individual will comply with certain requirements or align with the wishes of those around them during the behavior process (Ajzen, 1991). Therefore, the willingness to pay for environmental services offered by tourism enterprises depends on people and the surrounding factors. Based on these arguments, the research hypothesis is proposed as follows:

H2: Subjective norms positively influence the intention to pay for environmental services in tourism enterprises.

Perceived behavioral control refers to an individual's subjective or objective assessment of their ability to perform a specific behavior, which depends on the resources and opportunities available to them (Ajzen, 1991). The studies by Chen and Chang (2012), Nguyen and Uong (2025), also argue that people who care about the environment only display environmentally friendly behavior if they believe that a single person's actions can help solve common environmental issues. Based on these arguments, the research hypothesis is proposed as follows:

H3: Perceived behavioral control positively influences the intention to pay for environmental services in tourism enterprises.

Environmental concern, as a psychological state, exists within each individual who is emotionally connected to their current environment (Chan et al., 2014; Khumalo et al., 2025). It establishes a strong connection between customers' concern for the environment, their intention to purchase green and organic products, goods, or services, and their efforts to reduce emissions that harm the natural environment, thereby protecting their health and promoting sustainable economic development (Zhao et al., 2014). Research by Wei et al. (2018) and Yue et al. (2020) highlighted that environmental concern is a key factor in encouraging the selection of products, goods, or services that meet environmental protection standards. This view is also supported by various studies conducted by Joshi and Rahman (2015), and Do et al. (2023). Based on these arguments, the research hypothesis is proposed as follows:

H4: Environmental concern positively influences the intention to pay for environmental services in tourism enterprises.

Perceived green consumption refers to individuals' awareness of their responsibility toward the community and the environment, aiming to maintain the integrity of the natural ecosystem through their behaviors, especially when consuming or purchasing environmentally friendly products, goods, or services (Xie et al., 2022; Baláková et al., 2024).

Sun et al. (2019) and Masárová and Kordoš (2025) suggest that highly educated and knowledgeable individuals are more likely to act in an environmentally friendly way or be willing to pay higher prices for green products, goods, or services. It indicates that consumers with deep environmental awareness tend to shift from traditional consumption habits to green consumption to reduce their negative impact on the environment and act more responsibly during the purchase of products, goods, or services (Testa et al., 2021; Łęgowik-Małolepsza et al., 2024). Perceived green consumption is also influenced by customers' accumulated experience and knowledge gained from using green products, goods, or services, making them aware of the safety for their own health and society, especially in promoting environmental protection or changing consumption habits that cause pollution (Ho et al., 2019). Based on these arguments, the research hypothesis is proposed as follows.

H5: Perceived green consumption positively influences the intention to pay for environmental services in tourism enterprises.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/p3395468557

The study by Cai et al. (2020) shows that the expectation of a good life is a key desire for customers when choosing products, goods, or services that are safe, easy to recycle, and minimize environmental pollution. This desire stems from the desire to protect future generations who will enjoy a green, healthy environment and a better quality of life. Customers' intentions for green consumption depend on their thoughts about the future. Currently, they tend to choose green products, goods, or services and adopt eco-friendly lifestyles to ensure a better future for the next generation. Additionally, the expectation of a good life positively influences the intention to use green products or services. Based on these points, the research hypothesis is proposed as follows:

H6: Expectation of a good life positively influence the intention to pay for environmental services in tourism enterprises.

According to Prime Minister's Decision No. 1393/QD-TTg dated September 25, 2012, which approves the Green Growth Strategy for the 2011-2020 period and the vision to 2050, the strategic task for implementing the Green Growth Strategy is: "Greening production and greening lifestyles and promoting sustainable consumption." Greening production involves implementing a clean industrialization strategy through reviewing and adjusting existing sectoral planning, using resources in an economical and efficient manner, encouraging the development of green technology, and fostering green agriculture with environmentally friendly structures and technologies. Additionally, greening lifestyles and promoting sustainable consumption means encouraging individuals, enterprises, and organizations to use environmentally friendly products. Thus, the policy to promote the green development of enterprises and organizations is a set of measures, regulations, and supports from the government designed to encourage them to adopt environmentally friendly production and business models, advancing sustainable development. Promoting policies include financial and tax support, technology assistance, support for recycling and reusing raw materials, environmental regulations, and the expansion of green markets, which help enterprises minimize their environmental impact and enhance competitiveness. Monetary and non-monetary policies influence individuals' intentions to purchase environmentally friendly green products, goods, or services (Börner et al., 2017; Huang & Ge, 2019). Based on these arguments, the research hypothesis is proposed as follows:

H7: Government policies positively influence the intention to pay for environmental services in tourism enterprises.

3. Methodology

3.1. Measurement scales

The overall results of domestic and international studies serve as a foundation for developing a preliminary scale. The authors held a group discussion with managers or owners of tourism enterprises in the Mekong Delta and conducted in-depth interviews with several tourism experts to evaluate the scale's content, adjust the number of observed variables, and refine the wording to ensure that the preliminary scale aligns with the research objectives, survey participants, and the research environment. Each interview lasts approximately 15 minutes, conducted by phone with the respondents. The interviews took place in mid-November 2024. After this process, the study achieved the highest consensus among participants for the final scale, which includes seven independent factors and a dependent factor comprising 36 observed variables. The study utilized a five-level Likert scale, ranging from Level 1 – Strongly disagree to Level 5 – Strongly agree. Furthermore, the authors conducted a test scale using Cronbach's Alpha analysis and exploratory factor analysis (EFA) with SPSS 26 software to ensure integrity before performing formal data analysis (see Table 1).

Table 1. Results of preliminary scale test

Scales	No.	Cronbach's Alpha	Smallest factor loading	Adopted
Attitudes	5	0.825	0.784	Ajzen (1991), Do et al. (2023), the authors
Subjective norms	5	0.817	0.773	
Perceived behavioral control	5	0.829	0.782	
Environmental concern	5	0.803	0.765	Chan et al. (2014), Yue et al. (2020), Ha et al. (2022), the authors
Perceived green consumption	5	0.811	0.759	Cherian and Jacob (2012), the authors
Expectation of the good life	5	0.819	0.768	Cai et al. (2020)

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2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/p3395468557

Scales	No.	Cronbach's Alpha	Smallest factor loading	Adopted
Government policies	5	0.808	0.761	Huang and Ge (2019), Dang and Hoang (2019), Nguyen et al. (2023), the authors
KMO = 0.723, Sig. = 0.000 Eigenvalue = 1.683, % of Variance = 72.839%				
Intention to pay for environmental services	1	0.834	0.798	The authors
KMO = 0.705, Sig. = 0.000 Eigenvalue = 2.134, % of Variance = 74.172%				

Source: Analysis results from SPSS 26

The results in Table 1 show that both independent and dependent factors have a Cronbach's Alpha above 0.8 and a Corrected Item-Total Correlation greater than 0.4. This indicates that no observed variables were removed from the scale and that it meets the criteria for reliability, internal consistency of each scale, and observed variables explaining significant factors in the scale. Additionally, the exploratory factor analysis (EFA) results reveal that the observed variables have factor loadings greater than 0.7, demonstrating the sound quality (see Appendix). Additionally, the KMO coefficient is 0.7, which is considered significant, and the Sig coefficient of the Bartlett test is less than 0.001. At an Eigenvalue cutoff of greater than 1.0, seven independent factors are extracted, accounting for a total variance of 72.839%, consistent with the original predicted groups. For the dependent factor, there is a single observed variable, and the Eigenvalue exceeds 2, explaining a total variance of 74.172% allocated to one factor. Therefore, the scale meets the requirements for conducting a formal survey.

3.2. Data collection

The survey is created on Google Doc to ensure the participants' identities remain secure, allowing online surveys to be conducted through chat applications and email. The participants are managers or owners of tourism enterprises in the Mekong Delta region, selected using a convenient non-probability sampling method to gather as many responses as possible in the shortest time from December 2024 to February 2025. The collected data was analyzed using SmartPLS 4.0 software to test the hypotheses in the proposed research model and the path coefficients. The PLS-SEM technique has the advantage of performing analyses with small sample sizes in the range of 100 to 300 samples (Hoyle, 1995), so it is suitable for this study. The authors distributed 260 questionnaires and recovered 211 usable ones after removing invalid responses, yielding a response rate of 81.1 percent. Out of the 221 respondents, 74.3 percent were male, 25.7 percent female, and all were between 40 and 50 years old with a university degree or higher. Tourism enterprises operating for less than 5 years with revenues over 500 million VND made up 62 percent, while those operating for more than 5 years with revenues over 1 billion VND accounted for 28 percent. More than 89.7 percent of tourism enterprises are aware of how to pay for environmental services, but only 41.2 percent offer green tourism products. Tourism enterprises attract 61.6 percent of international visitors to Vietnam and have a demand for green tourism products.

4. Research results

4.1. Measurement model analysis

The analysis results in Table 2 show that the scale demonstrates intrinsic consistency reliability, with Cronbach's Alpha coefficients and composite reliability of factors exceeding 0.8. Additionally, an Average Variance Extracted (AVE) greater than 0.5 indicates the scale has convergent validity. Furthermore, the lowest outer loading coefficient of the observed variables, which is above 0.7, confirms that they are of good quality and appropriate for further analysis.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/p3395468557

Table 2. Reliability and convergent validity

Measurement scales	Reliability		Convergent	Smallest
	Cronbach's Alpha	CR	AVE	outer loading
Attitudes	0.828	0.897	0.715	0.786
Subjective norms	0.821	0.893	0.712	0.780
Perceived behavioral control	0.832	0.908	0.721	0.792
Environmental concern	0.805	0.877	0.684	0.754
Perceived green consumption	0.814	0.885	0.702	0.773
Expectation of the good life	0.816	0.889	0.709	0.767
Government policies	0.810	0.881	0.695	0.789
Intention to pay for environmental services	-	-	-	1.000

Source: Analysis results from SmartPLS 4.0

The analysis results in Table 3 show that the scale achieves discriminant validity because the correlation coefficient of each factor is in the range of 0.827 to 0.854 (with a statistical significance level of less than 0.01). Additionally, the crossroad coefficients are the second root of the AVE coefficient of each factor and are greater than the correlation coefficients of each other factor pair. Besides, the correlation coefficient between the pairs of factors is less than the aggregate reliability, which supports the judgment that the scale achieves its discriminant validity.

Table 3. Discriminant validity (Fornell – Larcker)

Scales	Att	SN	PBC	EC	PGC	Exp	GP	Int
Att	**0.845*****							
SN	0.605***	**0.844*****						
PBC	0.582***	0.675**	**0.849*****					
EC	0.371**	0.442***	0.492**	**0.827*****				
PGC	0.776**	0.532***	0.388***	0.704***	**0.838*****			
Exp	0.529**	0.509**	0.660**	0.348***	0.456**	**0.842*****		
GP	0.643***	0.622***	0.547***	0.463***	0.642**	0.586***	**0.834*****	
Int	0.724**	0.478**	0.451***	0.694***	0.354***	0.513***	0.455**	**1.000**

*Note: **significant at p < 0.01, ***significant at p < 0.001*
Att = Attitudes, SN = Subjective norms, PBC = Perceived behavioral control, EC = Environmental concern, PGC = Perceived green consumption, Exp = Expectation of the good life, GP = Government policies, Int = Intention to pay for environmental services

Source: Analysis results from SmartPLS 4.0

The results in Table 4 further confirm the discriminant validity of the scales, as shown by the correlation coefficients between factor pairs being less than 0.8 with a significance level below 0.01 (Hair et al., 2019).

Table 4. Discriminant validity (HTMT)

Scales	Att	SN	PBC	EC	PGC	Exp	GP	Int
Att								
SN	0.285***							
PBC	0.468***	0.573***						
EC	0.502***	0.287**	0.384**					
PGC	0.337**	0.374**	0.249***	0.679**				
Exp	0.485***	0.460***	0.471***	0.714**	0.392***			
GP	0.431**	0.562**	0.347**	0.576***	0.257***	0.685**		
Int	0.664**	0.608**	0.262**	0.523**	0.427**	0.736***	0.396***	

*Note: **significant at p < 0.01, ***significant at p < 0.001*
Att = Attitudes, SN = Subjective norms, PBC = Perceived behavioral control, EC = Environmental concern, PGC = Perceived green consumption, Exp = Expectation of the good life, GP = Government policies, Int = Intention to pay for environmental services

Source: Analysis results from SmartPLS 4.0

4.2. Structural model analysis

The analysis results in Table 5 indicate that the hypotheses have a VIF coefficient of less than 4, suggesting that the multicollinearity phenomenon does not occur (Hair et al., 2019). In addition, f2 greater than 0.2 supports

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/p3395468557

the hypothesis that independent factors have a positive and significant influence on the dependent factor (Hair et al., 2019).

Table 5. VIF and effect size

Hypothesis	VIF	f^2	Effect size
H1	1.583	0.412	Large
H2	1.165	0.395	Large
H3	1.984	0.406	Large
H4	3.244	0.284	Medium
H5	2.751	0.217	Medium
H6	3.672	0.364	Large
H7	3.835	0.378	Large

Source: Analysis results from SmartPLS 4.0

The analysis results in Table 6 show that the corrected R^2 reaches 0.798, indicating that independent factors significantly explain the variance in dependent factors. Additionally, the adjusted R^2 also reaches 0.798, close to 1, reflecting a strong explanatory power of the independent factors for the dependent ones. Conversely, values closer to 0 suggest a lower level of explanation (Hair et al., 2019). The Q^2 coefficient of 0.524 signifies a high level of accuracy in predicting dependent factors from the independent ones or in the overall structural model's predictive power (Hair et al., 2019). Simultaneously, the SRMR coefficient of less than 0.1 confirms the suitability of the structural model with data collected from enterprises in the tourism sector in the Mekong Delta (Hu & Bentler, 1999).

Table 6. Saturated model results

Scale	R^2	Adjusted R^2	Q^2
Intention to pay for environmental services	0.812	0.798	0.524
SRMR		0.068	

Source: Analysis results from SmartPLS 4.0

The study employed the bootstrapping method with a sample size repeated 2000 times to test the research hypothesis (see Table 7).

Table 7. Hypothesis testing

Hypothesis	β	SE	t	Conclusion
H1	0.317	0.037	3.462^{***}	Supported
H2	0.302	0.042	3.054^{***}	Supported
H3	0.314	0.036	3.241^{***}	Supported
H4	0.189	0.051	4.553^{**}	Supported
H5	0.218	0.046	3.956^{**}	Supported
H6	0.283	0.040	2.758^{**}	Supported
H7	0.346	0.041	4.113^{***}	Supported
*Note: **significant at p < 0.01, ***significant at p < 0.001*				

Source: Analysis results from SmartPLS 4.0

Figure 2 presents the structural model of the hypothesis research framework.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/p3395468557

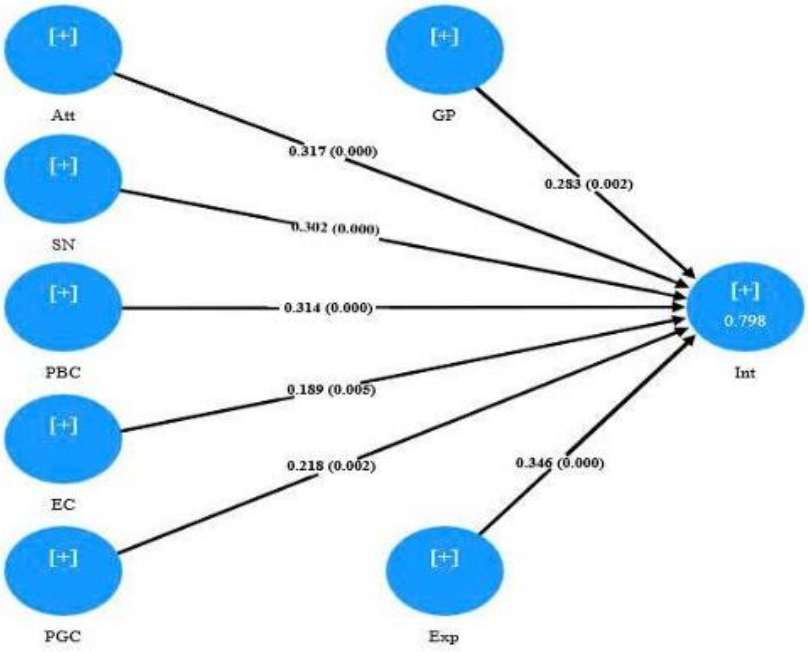


Figure 2. Structural model
Source: Analysis results from SmartPLS 4.0

The results of estimates from 2000 observations indicate that the original weights are meaningful to the mean weighting of bootstrapping, as they fall within the 95% confidence interval. 'Attitudes' ($\beta = 0.317$, $p < 0.001$), 'Subjective norms" ($\beta = 0.302$, $p < 0.001$), 'Perceived behavioral control' ($\beta = 0.314$, $p < 0.001$), 'Environmental concern' ($\beta = 0.189$, $p < 0.01$), 'Perceived green consumption' ($\beta = 0.218$, $p < 0.01$), 'Expectation of the good life' ($\beta = 0.283$, $p < 0.01$), and 'Government policies' ($\beta = 0.346$, $p < 0.001$) have a significant impact on the intention to pay for environmental services of tourism enterprises in the Mekong Delta.

5. Discussion and implications

The study has shown that attitudes, subjective norms, perceived behavioral control, environmental concern, perceived green consumption, expectations of a good life, and government policies positively influence the intention to pay for environmental services in tourism enterprises. This result is consistent with Do et al. (2023), Nguyen and Nguyen (2024), Huang and Ge (2019).

Government policies have the most direct and strongest influence on the intention of tourism enterprises in the Mekong Delta to pay for environmental services. This aligns with the characteristics of the Mekong Delta, which is heavily affected by climate change, resource depletion, and environmental pollution. Therefore, the Vietnamese Government tends to prioritize policies that protect the environment and preserve the ecosystem more than in wealthier regions. It makes the intention to pay for environmental services by tourism enterprises here more directly influenced by government policies than in other regions. More importantly, most tourism enterprises in the Mekong Delta are small and medium-sized, so their awareness of environmental responsibility is limited, and they mostly act based on policy pressure rather than voluntarily. Therefore, the government's policies play a decisive role in their willingness to pay for environmental services. The government should develop policies tailored for small and medium-sized enterprises by establishing flexible contribution levels based on revenue size, helping enterprises avoid financial burdens when paying for environmental initiatives. Additionally, local governments should organize training programs and seminars to explain the benefits of environmental payment services for long-term business operations, sharing successful models and the economic benefits of participating in environmental service payments.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/p3395468557

Next, the attitude was found to have a significant positive impact on the willingness to pay for environmental services among tourism enterprises in the Mekong Delta. When enterprises have a positive attitude, they are more likely to be willing to pay for environmental services. Therefore, local authorities need to organize communication campaigns that emphasize the importance of paying for environmental services in protecting tourism resources, contributing to sustainable development and enhancing the image of "green" enterprises in the minds of customers. Additionally, it is important to enhance environmental awareness education and training by offering environmental knowledge and sustainable tourism courses for business owners and managers. Furthermore, the government should conduct regular surveys on enterprises' environmental attitudes and perceptions to identify trends and changes, develop policies, and craft effective communication messages to encourage business owners in the Mekong Delta to support paying for environmental services.

Finally, perceived behavioral control was found to have a significant positive effect on the intention of tourism enterprises in the Mekong Delta to pay for environmental services. When tourism enterprises feel they have the ability, resources, and conditions to pay for environmental services, their intention increases. Therefore, local authorities need to strengthen the capacity and knowledge of tourism enterprises by organizing training courses, in-depth seminars on environmental services, and providing simple, easy-to-apply practical manuals to help enterprises understand the process and reduce feelings of ambiguity and difficulty. Additionally, local authorities should simplify administrative procedures related to the registration and payment of environmental services and establish a one-stop mechanism for technical support and advice during the payment process. Moreover, designing financial support packages such as tax exemptions and reductions, along with green credit incentives for enterprises that pay for environmental services, is essential.

Conclusion

Research on the intention to pay for environmental services has become a topic that attracts many scholars' attention, but there is very little literature on the intention to pay for environmental services by enterprises in the tourism sector. Theoretically, the results from this study contribute to understanding the factors influencing willingness to pay for environmental services in the tourism sector by highlighting the impact of individual factors of business owners, including attitudes, subjective norms, perceived behavioral control, environmental concern, perceived green consumption, and expectations of a good life. Therefore, the study applied the expanded TPB to explain the mechanism that leads to the formation of the intention to pay for environmental services of tourism enterprises and to empirically demonstrate that attitudes and perceptions of behavioral control positively influence the intention to pay for environmental services in the Mekong Delta. Consequently, promoting positive attitudes and awareness of behavioral control helps enhance the future willingness of tourism enterprises to pay for environmental services.

More importantly, the novelty of this study is in discovering that government policies play the most positive role in shaping the intentions of tourism enterprises to pay for environmental services in a socialist state governed by the rule of law, such as Vietnam, unlike in capitalist countries. This result confirms the central role of the state, with its policy considered a key lever to promote compliance and increase awareness of environmental responsibility among enterprises in Vietnamese conditions. In such a context, where the State has a strong influence on socio-economic regulation, administrative and legal tools continue to play a decisive role in shaping corporate behavior, especially regarding public interests like environmental protection.

Practically, the results of this study help local governments in the Mekong Delta understand the factors that influence tourism enterprises' willingness to pay for environmental services. Although the study presents interesting findings, it also has some limitations. First, data was collected from only one region of Vietnam, so the results cannot be generalized to other parts of the country. Second, because this study used cross-sectional data, there may be some bias in sampling. Therefore, future research should broaden the scope and include longitudinal data collection.

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Appendix. Outer loadings

Scales	Sign	Outer loadings
Attitudes	Att1	0.867
	Att2	0.786
	Att3	0.800
	Att4	0.845
	Att5	0.813
Subjective norms	SN1	0.780
	SN2	0.803
	SN3	0.816
	SN4	0.843
	SN5	0.819
Perceived behavioral control	PBC1	0.808
	PBC2	0.844
	PBC3	0.792
	PBC4	0.830
	PBC5	0.810
Environmental concern	EC1	0.788
	EC2	0.829
	EC3	0.790
	EC4	0.811
	EC5	0.754
Perceived green consumption	PGC1	0.799
	PGC2	0.773
	PGC3	0.821
	PGC4	0.837
	PGC5	0.793
Expectation of the good life	Exp1	0.809
	Exp2	0.849
	Exp3	0.824

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2025 Volume 13 Number 2 (December)
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Scales	Sign	Outer loadings
	Exp4	0.767
	Exp5	0.788
Government policies	GP1	0.835
	GP2	0.827
	GP3	0.789
	GP4	0.795
	GP5	0.806
Intention to pay for environmental services	Int	1.000

Source: Analysis results from SmartPLS 4.0

Data Availability Statement: More information and data can be found from the authors on a reasonable request.

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ACCEPTANCE OF ARTIFICIAL INTELLIGENCE TECHNOLOGY IN THE RECRUITMENT PROCESS OF SLOVAK ENTERPRISES

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Abstract. Artificial intelligence is playing an increasingly important role in human resource management, with recruitment being the area where its benefits are most visible. The purpose of this article is to examine how Slovak enterprises adopt AI technologies in their recruitment processes. The analysis is based on a survey of 434 responses, covering companies of different sizes, industries, and regional presence. The findings show that a higher level of knowledge and perceived benefits significantly increase the likelihood of AI implementation, while reported barriers did not prove to be statistically significant. AI adoption therefore appears as a complex process that cannot be explained only by technological advantages but is also shaped by organizational capacities, the level of digital literacy, and the impact of the regulatory environment. To address this complexity, the combination of the Technology Acceptance Model (TAM), which emphasizes perceived benefits and ease of use, and the Technology-Organization-Environment (TOE) framework, which adds a perspective on organizational and environmental factors, proves to be particularly appropriate.

Keywords: artificial intelligence (AI); recruitment; human resource management; technology acceptance; Technology Acceptance Model (TAM); Technology-Organization-Environment (TOE)

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JEL Classifications: M12, M15, O33

1. Introduction

In recent years, business practice has witnessed a dynamic development of digital technologies that fundamentally reshape how organizations operate. Among the most commonly applied solutions are big data processing, cloud computing (Alenezi, 2021), the Internet of Things (IoT) (Horak et al., 2022), blockchain (Kimani et al., 2020), and various forms of advanced data analytics (Mohammed et al., 2025; Gimmelberg et al., 2025). These technologies enable companies to process information more effectively, optimize decision-making, and respond more flexibly to changing market conditions. A similar trend can be observed in the public sector, where such solutions form the basis of smart city concepts aimed at more efficient management of transport, energy, and citizen engagement (Koman et al., 2024). At the same time, methods of modeling complex systems and analyzing graph structures are being applied (Dudáš, Lauko, 2025), highlighting the growing importance of linking both business practice and the public sector with modern computational approaches. An essential aspect of this development is the deepening collaboration between humans and machines (Beňo, Ölvecký, 2024; Mugunzva, Manchidi, 2024), which allows the computational power of technology to be combined with human experience, intuition, and value-based judgment. Among all technologies, artificial

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intelligence has become the most prominent, establishing itself as a key driver of digital transformation and permeating diverse areas of management.

Current scientific research points to a profound transformation of human resource management under the influence of digitalization (Zavyalova et al., 2022; Ma, 2023; Štaffenová et al., 2025). Whereas earlier studies describe the use of primarily administrative systems (Ball, 2001; Kovach et al., 2002; Lengnick-Hall, Moritz, 2003), more recent works emphasize the rise of digital platforms enriched with elements of artificial intelligence (Bar-Gil et al., 2024; Komarova et al. 2024; Khushk et al., 2025). In the field of recruitment, this shift is reflected in the use of automated CV screening, chatbots, and video interview analysis (Albassam, 2023). Researchers generally agree that these tools deliver greater speed and consistency (Yanamala, 2021; Ahmadi et al., 2024), but they also raise questions related to transparency, data protection, and the fairness of algorithmic decision-making (Charlwood, Guenole, 2022; Rao, Zhao, 2025). At the same time, studies reflect regulatory measures of the European Union, which classify AI systems used in recruitment as high-risk (Gruchała et al., 2025). In this context, the need to examine not only the technological benefits but also the degree of organizational acceptance of such solutions is emphasized (Calluso, Devetag, 2024; Islam et al., 2024). This is particularly relevant in Slovakia, where the topic remains relatively new and underexplored.

The use of artificial intelligence in recruitment processes has already been examined relatively extensively in the international literature, whether from the perspective of efficiency, ethics, or technological readiness (Albassam, 2023; Pechová et al., 2024; Kim et al., 2025). Anyway, in the Slovak context it remains a relatively new and underexplored research problem. Systematic empirical data are lacking on the extent to which companies employ these technologies, the factors influencing their acceptance, and the barriers preventing their broader implementation. The absence of such knowledge hampers not only academic debate but also the practical decision-making of managers, who face the pressures of digitalization while having to account for the legislative, financial, and cultural specificities of the Slovak environment.

The aim of this study is to examine how Slovak enterprises adopt artificial intelligence technologies in the recruitment process. Particular attention is given to identifying the factors that influence their acceptance by organizations and HR professionals, as well as the barriers that slow down or prevent the implementation of these solutions. The ambition is to provide a comprehensive picture of the current situation in Slovakia and to create a basis for recommendations that can contribute to the responsible and effective integration of AI into human resource management practice.

The contribution of this study lies in providing empirical data and conceptual insights into the acceptance of artificial intelligence in the recruitment process within the Slovak context. The results may expand the existing academic debate while also offering practical recommendations for managers and HR professionals. The knowledge gained can support not only more effective adoption of AI in HR processes but also its ethical and transparent implementation in line with the European regulatory framework.

2. Literature Review

Recruitment is one of the key HR processes that significantly influences the performance and competitiveness of enterprises. Traditional forms of selection, based on manual screening of résumés or face-to-face interviews, are time- and resource-intensive (McKnight et al., 2015). Over the past decade, this area has undergone rapid digitalization, with one of the most prominent trends being the use of artificial intelligence (Li et al., 2021).

Previous research (Upadhyay, Khandelwal, 2018; Black, van Esch, 2020) has shown that AI can significantly accelerate and streamline various stages of recruitment. Algorithms enable the automated screening of large volumes of résumés, chatbots can answer common candidate questions or conduct initial screenings, and image and voice recognition systems are used to analyze video interviews (Thakur et al., 2023). This reduces the administrative burden on HR professionals while increasing the consistency of decision-making. On the other hand, the scientific literature also highlights the risks associated with the use of AI. These include algorithmic bias (Alsubaie, Aleisa, 2025), insufficient transparency in decision-making (Yanamala, 2023) and concerns over data protection (Kassir et al., 2023). Several empirical studies point to cases where algorithmic systems have

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2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/c6223846445

reproduced existing discriminatory patterns or favored certain groups of applicants based on hidden data correlations (Andrews, Bucher, 2022; Chen, 2023; Morin, 2024).

In response to the risks associated with the use of AI systems, the European Commission introduced the AI Act, which classifies artificial intelligence systems used in recruitment as high-risk applications (Sunyaev et al., 2025). This means that employers and HR technology providers will be required to meet strict standards concerning data quality, model transparency, human oversight of decision-making, and mechanisms for detecting and eliminating discrimination. Although these regulatory requirements create a framework for trustworthy and safe use of AI, they do not in themselves guarantee its adoption in practice. Evidence from prior research (Laurim et al., 2021; Hosain et al., 2025; Ilham, 2025) shows that technology acceptance depends not only on technical features and legal compliance but also on user attitudes, whether from employers, HR professionals, or job candidates. These aspects, which lie at the heart of the debate on trustworthy AI, emerge as key factors shaping the level of acceptance. In other words, regulatory frameworks may set minimum standards, but only when these principles are perceived as trustworthy by all stakeholders will the technologies achieve broader adoption. For this reason, it is essential to examine not only the technical benefits of such systems but also the extent to which they are accepted by companies and candidates.

Current research in this field is increasingly focused on ethical considerations, candidate trust, and the legitimacy of AI-assisted decisions. As prior studies demonstrate (van Esch et al., 2019), candidates trust in the fairness of the recruitment process directly affects their willingness to apply for a position and to continue engaging with the organization. At the same time, companies perceive AI as a tool that provides speed and efficiency but requires robust rules for responsible use. This suggests that artificial intelligence in recruitment is not merely a technological innovation but represents a fundamental paradigm shift in human resource management. It holds the potential to enhance the quality of decision-making while simultaneously raising questions of ethics, fairness, and legal accountability.

Specifics of the Slovak Context

Empirical evidence signals a significant shift in the use of artificial intelligence in human resources on a global scale. According to a study by The Hackett Group, as many as 66% of HR departments already employ generative AI to streamline human capital management, with 52% of organizations using it to draft job descriptions and 39% to screen résumés (Hackett Group, 2025). Similarly, a survey by CultureAmp shows that in January 2024, approximately 42% of HR teams were actively using AI across various activities (Boogaard, 2025). These figures confirm that in advanced economies such as the United States, Western Europe, and Asia, AI adoption in HR is progressing rapidly, with a strong emphasis on sophisticated tools based on machine learning and predictive analytics.

Research from Central and Eastern Europe, however, points to a different attitude toward AI adoption in enterprises. A report by the AI Chamber, based on a survey of more than 3 200 small and medium-sized enterprises, revealed that although more than 75% of firms claim to use AI, in practice only about 25% apply it systematically and on a larger scale (Stefanova, 2025). This gap between declared use and actual implementation reflects a more conservative approach to adopting new technologies. Moreover, lower trust in algorithmic decision-making and a preference for personal interaction from both candidates and employers increase the need to combine modern technologies with traditional practices and to maintain a strong human element in the recruitment process. It becomes evident that the acceptance of AI in recruitment is not determined solely by the availability of technologies but also by cultural expectations, levels of trust, and the broader context in which these solutions are introduced.

Technology Acceptance Models

Research on technology acceptance focuses on how individuals adopt and use new digital tools and systems. In the field of information and communication technologies, this line of inquiry is particularly concerned with the factors that influence the level of use, ranging from perceived usefulness and ease of use to social and organizational determinants. The most widely known framework is the Technology Acceptance Model (TAM), which emphasizes the role of perceived usefulness and perceived ease of use (Marangunić, Granić, 2015). Later extensions (TAM2, TAM3, and UTAUT) incorporated additional aspects such as social influence, individual

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
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experience, and contextual specificities. These models provide a solid theoretical foundation for examining the acceptance of artificial intelligence in recruitment processes, as they explain why HR professionals, managers, or candidates may choose to adopt or reject a given technology. An overview of the main Technology Acceptance Models and their key variables is presented in Table 1.

Table 1. Overview of Technology Acceptance Models

Model	Key Variables / Factors	Characteristics
TAM	- Perceived Usefulness - Perceived Ease of Use	Basic model explaining that technology adoption depends on its usefulness and ease of use.
TAM2	- Social influences (subjective norms) - Cognitive processes (image, job relevance, output quality, result demonstrability)	Extension of TAM that incorporates social factors and perceptions of output quality.
TAM3	- Perceptions related to ease of use (computer self-efficacy, perceptions of external control, anxiety, enjoyment)	Model further developing the dimension of perceived ease of use.
UTAUT	- Performance Expectancy - Effort Expectancy - Social Influence - Facilitating Conditions - Moderators: age, gender, experience, voluntariness of use	Integrated model combining several approaches to technology acceptance.
UTAUT2	- UTAUT factors + new variables: hedonic motivation, price value, habit	Extended model that also takes into account the consumer context and behavior over time.

Source: the authors processed according to literature (Lala, 2014; Rondan-Cataluña et al., 2015; Lai, 2017)

In the field of recruitment, these acceptance models have proven useful for examining how HR professionals perceive the benefits and user-friendliness of AI systems, how their attitudes are shaped by organizational culture and social norms, and how such attitudes differ by demographics and experience (Kashi, Zheng, 2013; Calluso, Devetag, 2024; Almeida et al., 2025). Practical experience, however, shows that the identified determinants alone are not sufficient. In the context of AI, there is a growing emphasis on the need to include new variables such as trust, fairness, ethical aspects, and data protection (Figueroa-Armijos et al., 2023; Rane et al., 2024). These factors reflect the specific nature of artificial intelligence, where issues of fairness, accountability, and transparent data handling play a crucial role. At the same time, it has become evident that acceptance models primarily focus on the individual level, namely the attitudes of particular users (Yang, Yoo, 2004). They pay less attention to the broader context, which strongly influences the actual implementation of technologies in practice. This includes factors such as the level of national digitalization, regulatory frameworks (GDPR, AI Act), infrastructure availability, and the digital literacy of the workforce.

3. Methodology

The aim of the research is to examine how Slovak enterprises adopt artificial intelligence technologies in the recruitment process. Based on theoretical foundations and existing knowledge, the following research hypotheses were formulated:

- **H_1:** A higher level of knowledge about AI among employees and managers positively influences the acceptance and implementation of AI in recruitment processes.
- **H_2:** A lack of expertise and concerns about data protection represent significant barriers that reduce the level of acceptance of AI in recruitment processes.
- **H_3**: Greater perceived benefits of artificial intelligence in recruitment processes are associated with a higher willingness of enterprises to implement these technologies.

These hypotheses provide the basis for empirical testing of how organizations in Slovakia respond to technological innovations in recruitment and which factors play a decisive role in their adoption.

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2025 Volume 13 Number 2 (December)
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Research Design

The study was conducted as a quantitative survey using an online questionnaire distributed between September 1, 2024, and April 30, 2025. The aim was to obtain empirical data on the acceptance of artificial intelligence in recruitment processes within Slovak enterprises. For this reason, the target population consisted of HR managers, recruiters, and professionals responsible for recruitment in Slovak companies. The total population comprised 148 297 entities (according to business registers and databases in Slovakia as of September 1, 2024). To determine the minimum required sample size, a standard statistical calculation was applied. With:

- population size **N = 148 297**,
- confidence level of **95 % (Z = 1.96)**,
- margin of error **5 % (e = 0.05)**,
- and response proportion **p = 0.5** (most conservative estimate),

The minimum sample size was calculated at **384 respondents**.

Participants and Data Collection

All participants provided informed consent prior to participating in the study. Participation was entirely voluntary and anonymous. The respondents were informed about the purpose of the research, the approximate time needed to complete the questionnaire, and their right to withdraw at any time without any consequences. No personal identifiers or sensitive data were collected.

- Number of respondents contacted: **6 913**
- Number of completed questionnaires: **445**
- Response rate: **6.44 %**
- Final analyzed sample: **434 respondents** (after excluding incomplete responses)

This number exceeded the threshold required for statistical representativeness, thereby increasing the reliability of the results.

Ethical Approval

This study was conducted in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki declaration and its later amendments. Ethical approval was not required for this study, as it involved an anonymous online survey with no collection of personal or sensitive data. Respondents participated voluntarily and could withdraw at any time.

4. Results

The results of the questionnaire survey are based on 434 responses, which form the core of the analyzed sample. The participating companies varied in terms of size, industry, and regional distribution, providing a comprehensive view of the issue under study. In terms of company size, medium-sized (49%) and large enterprises (29%) had the strongest representation, together accounting for roughly three quarters of the sample. Small enterprises were represented to a lesser extent (22%). With respect to industry focus, manufacturing companies dominated (36%), followed by businesses in administrative services (8%), construction (7.6%), and transport and storage (7%). Other sectors, including trade, agriculture, and education, were also represented, although with lower intensity (below 5%). The regional distribution of respondents was relatively balanced. The largest number of responses came from the Žilina region (164) and the Banská Bystrica region (163). The Bratislava region also accounted for a significant share (140), while the lowest representation was recorded in the Prešov region (115). Overall differences between the regions, however, were not substantial, and the sample thus provides relatively even coverage of Slovakia's regions. The sample included both domestically operating companies and those with international reach. Nearly half of the respondents (46.8%) operate in foreign markets or are part of international groups, which makes it possible to observe the adoption of artificial intelligence not only in a national context but also in organizations connected to the international environment.

Respondents assessed their knowledge of artificial intelligence on a scale from 0 (no knowledge) to 10 (expert level). The results (Figure 1) showed that the overall level of knowledge was rather low to medium. The average rating was 4.29 and the median was 4, suggesting that most respondents did not consider themselves highly knowledgeable in this area. The most frequently chosen score was 5, corresponding to a medium level of knowledge. As many as 16 respondents (3.7%) indicated a score of 0, declaring a complete lack of knowledge

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2025 Volume 13 Number 2 (December)
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about AI. By contrast, only one respondent rated themselves at the maximum score of 10, while a score of 9 was not reported at all.

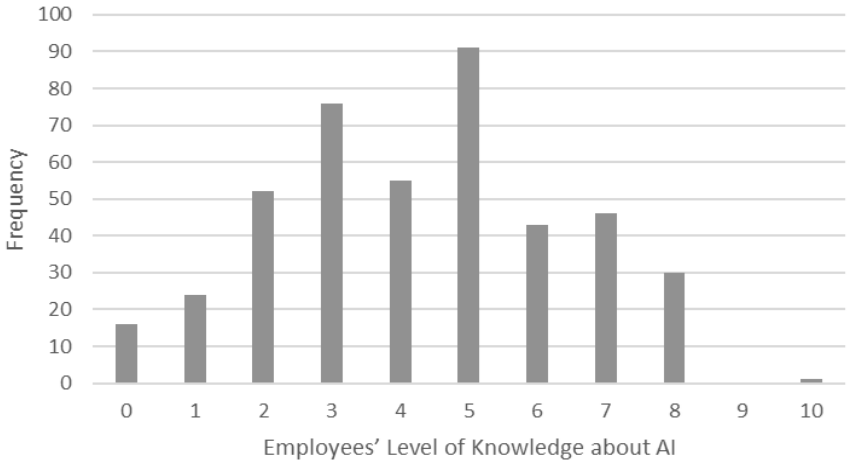


Figure 1. Distribution of Employees' Knowledge Levels about Artificial Intelligence

An interesting finding is that the declared level of knowledge varied slightly according to company size. In larger enterprises, the level of knowledge was higher (average 4.61), while in smaller firms lower ratings were more common (average 3.45). This result suggests that access to training opportunities and exposure to modern technologies may be more pronounced in larger organizations.

Verification of Hypothesis H_1

Hypothesis **H_1** assumed that a *higher level of knowledge about artificial intelligence among employees and managers positively influences the acceptance and implementation of AI in recruitment processes*. Respondents were divided into three categories according to their declared level of knowledge (low, medium, high), and their responses regarding AI implementation were analyzed in three categories (already implementing, planning to implement, not planning to implement). Figure 2 presents the distribution of companies according to their level of AI knowledge and implementation status, illustrating that higher knowledge levels are generally associated with greater readiness to adopt AI.

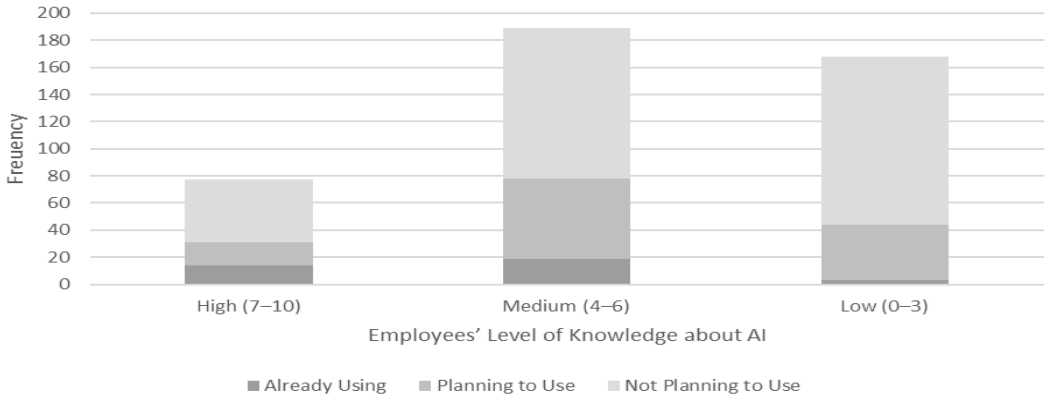


Figure 2. Companies' Attitudes toward the Use of AI in Recruitment Processes

The results of the chi-square test of independence showed a statistically significant relationship between the level of knowledge and AI implementation ($\chi^2 = 24.20$; $df = 4$; $p < 0.001$). Companies with a low level of knowledge predominantly declared that they do not plan to use AI (73.8%), while only 1.8% had already implemented it. In the medium knowledge group, the share of those planning implementation increased (31.2%), as did the share of those already implementing (10.1%). The most pronounced difference was observed in the high knowledge group, where although the majority of companies still reported no plans to implement AI (59.7%), the proportion of those already implementing rose to 18.2%.

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2025 Volume 13 Number 2 (December)
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These results **confirm the validity of Hypothesis H_1**, namely that a higher level of knowledge significantly increases the likelihood of acceptance and implementation of artificial intelligence in recruitment processes. The findings also indicate that the development of knowledge and competencies in AI represents a key factor supporting its broader adoption in practice.

Verification of Hypothesis H_2

Hypothesis **H_2** assumed that *a lack of expertise and concerns about data protection represent significant barriers that reduce the level of acceptance of AI in recruitment processes*. To test this hypothesis, a linear regression analysis was applied, with AI acceptance/implementation (binary coded) as the dependent variable and the declared barriers (concerns about data protection and lack of expertise) as the independent variables. The results of this analysis are presented in Figure 3, which summarizes the regression coefficients, standard errors, and significance levels for the tested variables.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0,060318071
R Square	0,00363827
Adjusted R Square	-0,000985219
Standard Error	0,478546225
Observations	434

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	0,360415041	0,180207521	0,786910105	0,455902244
Residual	431	98,70179694	0,229006489		
Total	433	99,06221198			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept	0,329309855	0,035153428	9,367787818	4,1773E-19	0,260216379	0,398403332	0,260216379	0,398403332
privacy_concerns	0,061275206	0,050846311	1,205106228	0,22882355	-0,03866237	0,161212782	-0,03866237	0,161212782
lack_of_experts	0,010625437	0,046171678	0,230128879	0,818100808	-0,080124227	0,1013751	-0,080124227	0,1013751

Figure 3. Results of Linear Regression Analysis on the Impact of Privacy Concerns and Lack of Experts on AI Adoption

The results showed that the model explained only a minimal share of the variability in AI acceptance (R^2 = 0.0036; 0.36 %). The test of statistical significance for the model as a whole confirmed that its explanatory power was insufficient (F = 0.79; p = 0.456). Neither concerns about data protection (β = 0.061; p = 0.229) nor lack of expertise (β = 0.011; p = 0.818) had a statistically significant effect on the acceptance of artificial intelligence in recruitment processes.

Based on these results, **Hypothesis H_2 was not confirmed**. The findings suggest that although these factors are often cited in the academic literature as barriers to AI adoption, their direct impact on implementation decisions was not empirically validated in the Slovak context. Interestingly, the coefficient estimates were even slightly positive, which would suggest the opposite trend, namely that companies declaring these barriers were more likely to implement or plan to implement AI. However, given the high p-values, this represents only a random effect without statistical significance. This outcome highlights the need to examine other determinants of adoption, particularly organizational and environmental conditions, which may have a more decisive influence on companies' decisions.

Verification of Hypothesis H_3

Hypothesis **H_3** assumed that greater perceived benefits of artificial intelligence in recruitment processes are associated with a higher willingness of companies to implement these technologies. In this study, willingness to implement was operationalized indirectly, based on company categorization according to their attitude toward the use of AI. Companies that reported no plans for implementation were classified as having low willingness, while those that planned implementation or were already using AI were classified as having demonstrated or declared willingness. Perceived benefits were measured through a benefits index that included assessments of factors such as time and cost savings, faster search and filtering of applicants, and better alignment of candidates with job positions. To test the relationship between perceived benefits and willingness to implement AI, a binary logistic regression was applied. The results of this analysis are presented in Figure 4, which summarizes the logistic regression output including coefficients, significance levels, and model fit indicators.

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2025 Volume 13 Number 2 (December)
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Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	536,73	,06	,08

Classification Table

			Predicted		
			using		
	Observed		0	1	Percentage Correct
Step 1	using	0	266	15	94,7%
		1	122	31	20,3%
	Overall Percentage				68,4%

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1	index_benefit	,57	,12	24,00	1	,000	1,78
	Constant	-2,44	,40	37,92	1	,000	,09

Figure 4. Impact of Perceived Benefits on AI Adoption

The results showed that the benefits index is a statistically significant predictor of willingness to implement (B = 0.57; Wald = 24.00; $p < 0.001$). The value Exp(B) = 1.78 indicates that with each one-point increase in the perceived benefits score, the probability of AI implementation increases by approximately 78%.

The model reached a Nagelkerke $R^2 = 0.08$, indicating that perceived benefits explain approximately 8% of the variability in company decision-making. The overall classification accuracy was 68.4%, with the model being more precise in identifying companies not planning to implement AI (94.7% correct) than those willing to implement (20.3% correct).

Based on these results, **Hypothesis H_3 was confirmed**. Higher perceived benefits of artificial intelligence are associated with a greater willingness of companies to implement these technologies. At the same time, the findings show that technological benefits explain only a small portion of the decision-making process. This insight underscores the need to understand the acceptance of artificial intelligence in recruitment as a complex phenomenon, influenced not only by perceived benefits but also by organizational and environmental factors, as reflected for example in the TOE framework.

5. Discussion

The research results were compared with three other empirical studies that also focus on the use of artificial intelligence in recruitment processes. Specifically, the comparison included the work of (Horodyski, 2023), the American survey AI in Hiring 2025 (InsightGlobal, 2025), and the global study conducted by (Boston Consulting Group, 2025). This comparative perspective makes it possible to place the Slovak findings within a broader international and practical context and to identify both common patterns and differences in AI adoption.

The first comparison can be made with the study by (Horodyski, 2023), which focused on the perception of artificial intelligence in recruitment processes from the perspective of job candidates. Both studies confirm that AI is generally perceived positively and is primarily associated with benefits such as time savings and greater process efficiency. In the Slovak context, this effect was reflected in the confirmation of perceived benefits as a factor increasing the likelihood of implementation, while Horodyski's respondents mainly valued faster responses and the ease of using AI tools.

Differences emerge in the perception of barriers. Slovak companies declared concerns about data protection and lack of expertise, but their statistical impact on adoption decisions was not confirmed. By contrast, Horodyski identified the main drawbacks as the absence of "human touch," lower accuracy, and technological immaturity. Ethical and legal aspects were also mentioned in his study, but they were not decisive factors. This difference suggests that companies are more likely to reflect regulatory and formal discourse, while candidates tend to evaluate the technology primarily based on its practical limitations.

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Another area of divergence lies in the importance of knowledge and competencies. The Slovak study confirmed that a higher level of knowledge among managers and employees increases the likelihood of AI implementation. Although Horodyski did not explicitly address this issue, his results indicate that digital literacy and the factor of candidate knowledge and experience significantly shape the way AI is evaluated.

Both studies therefore converge in identifying perceived benefits as a key factor in AI acceptance, but diverge in their assessment of barriers. At the same time, both reveal the existence of certain missing factors that influence the acceptance of AI.

A comparison of the Slovak survey with the American study *AI in Hiring 2025* (InsightGlobal, 2025) reveals fundamental differences in the level of adoption of artificial intelligence in recruitment processes. While in Slovakia the use of AI is still in a phase of gradual development and company decisions depend on their size, industry, and technological readiness, in the United States AI is already an established part of practice, with as many as 99% of hiring managers reporting that they actively use these tools. Both surveys, however, confirm that the main driver of implementation is the perceived benefits. Slovak companies that recognize these benefits show greater willingness to adopt AI, while in the US 98% of managers reported improved efficiency and 74% highlighted AI's contribution to assessing candidate–job fit.

Differences emerge in the area of barriers. In Slovakia, discussions focus mainly on regulation, transparency, and ethics, while concerns about data protection or lack of expertise did not prove to be decisive factors. At the same time, there remains a preference for traditional methods, signaling the need to maintain personal contact and human judgment. The American study confirms this aspect: 93% of hiring managers stressed that high-quality selection is not possible without the human factor, even though AI significantly accelerates processes.

An interesting difference is found in the perception of AI on the candidate side. In the US, more than half of managers indicated that they are uncomfortable with candidates using AI to prepare résumés or cover letters, as they view this as inauthentic. This aspect was not captured in the Slovak research but opens an important discussion about the acceptability of AI use from the candidates' perspective.

The results of the two studies therefore complement each other. In both cases, the significant benefits of AI for recruitment efficiency and quality come to the forefront, but the perceived barriers differ. Slovak companies emphasize regulatory and ethical issues, while American managers focus on balancing technological efficiency with the preservation of human involvement.

A comparison of the Slovak survey with the global study by (Boston Consulting Group, 2025) highlights both common trends and notable differences in the adoption of artificial intelligence in recruitment processes. In the Slovak context, AI implementation is still in its early stages and depends strongly on company size and the level of technological expertise. Larger organizations with greater competence in digital technologies are more willing to experiment, whereas smaller companies often continue to rely on traditional practices. Adoption decisions are mainly associated with perceived benefits such as time savings, more efficient candidate screening, and better alignment between applicants and job requirements. The global BCG survey confirms these benefits but on a much broader scale. As many as 70% of organizations experimenting with AI reported testing it in HR, most commonly in talent acquisition. According to the results, 92% of companies already perceive tangible benefits, and more than 10% have recorded productivity gains exceeding 30%. The most widespread applications include content creation (job ads, assessments), administrative tasks (interview scheduling), and candidate–job matching.

Differences between the studies are most evident in the area of barriers. Slovak companies emphasize regulation, transparency, and ethical aspects, while concerns about data protection or lack of expertise were not confirmed as decisive factors. Globally, however, the dominant issue is the candidate experience. More than half of respondents stated they would decline a job offer after a negative recruitment experience. BCG also highlights the importance of monitoring a rapidly evolving regulatory environment, from the European AI Act to privacy legislation in the United States.

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A common thread across both studies is the emphasis on the human factor. While Slovak companies express confidence in traditional methods and personal contact, global data emphasize the shift of recruiters away from routine administrative tasks toward relationship building and strategic planning. In both contexts, it is clear that successful AI implementation in recruitment is not merely a matter of technology but of integrating it in ways that preserve the human dimension while enhancing the candidate experience.

A comparison of the Slovak results with the three international studies shows that artificial intelligence in recruitment processes is primarily attributed practical value, such as time savings, greater efficiency, and more accurate candidate matching. All the analyzed surveys converge on this point. The differences, however, emerge in the perception of barriers: Slovak companies emphasize regulation and ethics, American managers stress the indispensability of the human factor, and global data highlight the quality of the candidate experience as a decisive element of success.

These differences suggest that the acceptance of AI cannot be understood solely through the lens of technological benefits. A combination of organizational capacities, user experience, and external regulatory frameworks also comes into play. This makes it appropriate to connect the perspective of the Technology Acceptance Model (TAM), which explains the importance of perceived benefits and ease of use, with the Technology–Organization–Environment (TOE) framework, which incorporates organizational and environmental conditions. Such an integration allows the research to move beyond individual attitudes toward a macro-level perspective that better explains under what conditions the implementation of AI in recruitment processes becomes realistic and sustainable.

In the Slovak and Central European context, this combined approach is particularly valuable, as AI adoption is strongly influenced not only by the personal attitudes of users but also by labor market specificities, the regulatory framework, and the overall level of digitalization.

Conclusions

The research conducted in Slovakia revealed that companies' willingness to implement artificial intelligence in recruitment processes is closely tied to how they perceive its benefits. Organizations that recognize time savings, more efficient candidate search, and better candidate–job matching demonstrate a significantly higher readiness for adoption. Knowledge and digital competencies of managers and employees also play an important role, as higher levels of expertise directly support the acceptance of AI in practice. By contrast, frequently cited barriers such as lack of expertise or data protection concerns did not prove to be decisive factors in the Slovak context.

These findings emphasize that AI adoption cannot be reduced merely to technological benefits. It is a multidimensional process in which technological aspects intersect with organizational capacities, the level of digital literacy, and the ability to respond to regulatory and societal demands. To capture this complexity, combining the Technology Acceptance Model (TAM), which explains the role of perceived benefits and ease of use, with the Technology–Organization–Environment (TOE) framework, which adds organizational and environmental perspectives, proves particularly useful. This integrated approach makes it possible to better understand the dynamics of AI implementation under different conditions and to explain cross-contextual differences more effectively.

The main limitations of this research lie in its focus exclusively on companies and recruitment professionals. While this provides a representative picture of organizational decision-making in the Slovak context, it does not capture the experiences and attitudes of job candidates, which strongly influence the success of AI implementation in practice. The geographically limited scope also does not account for the specificities of other countries or sectors. Furthermore, not all hypothesized barriers were confirmed statistically, suggesting that additional, yet unobserved variables also play a role in decision-making.

Future research should therefore broaden its attention to organizational factors such as corporate culture, leadership style, and financial capacity, while also integrating the candidate perspective, which emerges as highly relevant in international studies. Another essential dimension for further investigation is the systematic

monitoring of the impacts of evolving regulatory frameworks, particularly the European AI Act, which emphasizes transparent and responsible use of AI in HR.

On a practical level, the findings suggest that AI can be a powerful tool for enhancing the efficiency and quality of recruitment processes. However, its successful implementation goes beyond technical solutions. It requires a prepared organizational environment, systematic development of digital competencies, and the preservation of the human dimension, which remains an irreplaceable part of the hiring process.

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FACTORS AFFECTING DIGITAL ENTREPRENEURSHIP: A CASE STUDY OF VIETNAMESE WOMEN

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Abstract. Digital business has become a dominant trend in today's digital era. This study aims to explore and identify the key factors influencing digital entrepreneurship among Vietnamese women. A quantitative research approach was used, employing a structured questionnaire to survey 527 women entrepreneurs in Vietnam. The collected data were analyzed with SPSS 26 software. The results indicate that personal and professional characteristics, digital entrepreneurial capabilities, digital consumer behavior, digital infrastructure, digital interactions, and government policies all have a positive influence on digital entrepreneurship intentions. Of these, government policies have the most significant impact, while digital consumer behavior has the least influence. Based on these findings, the study offers several recommendations to better support and promote digital entrepreneurship among Vietnamese women.

Keywords: Digital entrepreneurship; digital technology; Vietnamese women

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JEL Classifications: L26, M13, M21

1. Introduction

Digital technology platforms in the digital economy era have become the centerpiece of modern business models, connecting people, businesses, devices, data, and processes worldwide. The convergence of the internet, mobile technology, and the Internet of Things (IoT) has created a borderless network of connections, enabling businesses to transcend geographical boundaries and overcome gender stereotypes to serve diverse production and consumption needs. The digitalization process demands quick, efficient, and reliable information exchange and data transmission, requiring entrepreneurs to be creative, possess problem-solving skills, and integrate data into business processes to meet customized supply chain requirements.

Although the current business community is still mostly composed of men, women entrepreneurs are gradually earning their place by expanding their activities in the online business sector, especially within small and medium-sized enterprises. To succeed, they must leverage technology, develop flexible and efficient processes, and acquire the right skills to benefit from advances in communications and data processing fully. This not only cuts transaction costs but also enables them to scale operations globally. With the trend of liberalizing trade policies and decreasing transportation costs due to IoT development, women entrepreneurs have opportunities to participate in global value chains where production processes are spread across multiple locations. The ability to adapt to technology and utilize global business networks will be essential for their success and sustainability.

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2025 Volume 13 Number 2 (December)
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Vietnam is a growing economy in Southeast Asia, experiencing rapid development of digital infrastructure, with over 70 percent of the population using the Internet and e-commerce achieving the region's highest growth rate. The government has launched the National Digital Transformation Strategy to 2025, with a vision extending to 2030, reaffirming its commitment to advancing the digital economy and innovation ecosystem. However, this progress is uneven between urban and rural areas, and a significant digital divide persists among social groups, especially between men and women.

Vietnamese women make up more than 70 percent of the workforce and have a high participation rate in start-ups within the region. However, most are concentrated in traditional industries such as retail or food service rather than digital technology sectors. Although the digital economy offers significant potential, women digital entrepreneurs in Vietnam still face many barriers, including limited technology skills, difficulty accessing capital and innovation support programs, and social prejudices about gender roles. While international studies have examined many factors influencing digital entrepreneurship, such as technological capacity, policy environment, and social and cultural networks (Sakhteh et al., 2024; Allawi & Alyouzbaky, 2025), empirical evidence from emerging economies like Vietnam remains limited, especially regarding research focusing on women.

This study addresses the research gap on digital entrepreneurship in developing countries and includes gender analysis to highlight the differences in opportunities and challenges faced by women entrepreneurs. Additionally, it offers valuable evidence for policymakers, training programs, capital assistance, and the development of networks focused on women digital entrepreneurs, thus supporting gender equality, enhancing national competitiveness, and unlocking women's potential in the digital economy.

2. Literature review and hypothesis development

2.1. Underlying theories

This study uses a multi-theoretical approach to examine the factors influencing the development of digital entrepreneurship among women entrepreneurs in Vietnam. The Resource-Based View (RBV) serves as the main theoretical foundation, supported by the social capital theory, digital consumer behavior theory, and public policy theory. Combining these perspectives provides a comprehensive understanding of how individual skills, technological resources, network dynamics, consumer behavior, and institutional support together shape digital entrepreneurial success.

While prior research has extensively explored digital entrepreneurship in developed economies (Autio et al., 2018; Belitski et al., 2023), there is a significant gap in the literature regarding the intersection of gender, digital skills, and institutional environments in emerging markets, especially in Southeast Asia. Additionally, few studies have used a resource-based theoretical approach to examine how women entrepreneurs develop and maintain digital ventures. This research fills this gap by applying the RBV and related theories to the Vietnamese context.

2.1.1. Resource-Based View (RBV)

The RBV developed by Barney (1991) argues that an enterprise's long-term competitive advantage stems from owning and strategically utilizing valuable, rare, inimitable, and non-substitutable resources. In digital entrepreneurship, these resources encompass digital entrepreneurial capabilities, digital infrastructure, human capital, and technological expertise.

This study uses the RBV as its main theoretical framework, asserting that women entrepreneurs' capacity to access and leverage these resources is crucial for the development and growth of digital ventures. Due to the fast-changing and growing nature of digital markets, resource agility and technological adaptation become essential for entrepreneurial success (Teece, 2018).

2.1.2. Social Capital Theory

Social Capital Theory, as described by Coleman (1988) and Putnam (2000), highlights the importance of social relationships, trust, and network structures in providing access to resources and opportunities. For women

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2025 Volume 13 Number 2 (December)
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entrepreneurs, particularly in patriarchal or male-dominated societies, social capital can make up for limited access to formal support systems (Brush et al., 2006).

This study examines social capital through digital engagement and participation in online communities, which offer emotional support, information exchange, and collaboration opportunities. These interactions boost entrepreneurial learning and help mobilize resources in the digital economy.

2.1.3. Digital Consumer Behavior Theory

The digital consumer behavior theory explores how technological advances influence consumer attitudes, decision-making, and buying habits. According to Hoyer et al. (2020), the growth of e-commerce, mobile devices, and social media has reshaped traditional consumption patterns.

This research applies this theory to explore how women entrepreneurs in Vietnam interpret and respond to changing digital consumer behaviors. Understanding such behaviors is crucial for creating effective products, services, and marketing strategies tailored to digitally engaged consumers.

2.1.4. Public Policy Theory

Public policy theory indicates that government regulations and institutional structures are crucial in shaping the entrepreneurial ecosystem. As Rodrigues and Franco (2021) point out, policies like digital training programs, tax incentives, and innovation subsidies can lower market entry barriers and promote entrepreneurial innovation. Although public policy is not the primary focus of this study, it is acknowledged as a crucial contextual factor that influences the availability of resources and the sustainability of digital entrepreneurship among Vietnamese women. Including this perspective enables a more comprehensive analysis of the external environment.

2.2. Hypotheses development

Personal factors, including personality, motivation, skills, and attitudes, play a crucial role in supporting digital entrepreneurship. Personality, in particular, helps entrepreneurs determine their intention and ability to start their own business (Sarwar et al., 2020; Latinytė, 2025), while intrinsic and extrinsic motivations foster autonomy, persistence, and positive attitudes toward technology (Koe & Sakir, 2020). Simultaneously, innovation capabilities and diverse skills, ranging from leadership and marketing to technology, are essential for competitiveness and success (Frese & Gielnik, 2014).

Digital entrepreneurial attitudes are considered the primary drivers, influenced by personal perceptions, social support, external pressures, and digital maturity (Gieure et al., 2019). Digital entrepreneurial intentions not only leverage technological opportunities but also boost economic growth (Aloulou et al., 2024). However, trust and risk-taking are also crucial. Digital entrepreneurship education helps entrepreneurs gain the knowledge, skills, and culture necessary to build successful projects. In a competitive digital environment, the ability to make quick decisions, adapt flexibly, and process information efficiently is key to success (Xing et al., 2020; Nurlatifah et al., 2025).

Digital entrepreneurs must continually improve their business models, develop their skills, and maintain an innovative mindset to stay ahead in a constantly changing market. Based on the above arguments, the research hypothesis is proposed as follows:

H1: Personal and professional characteristics have a positive influence on digital entrepreneurship.

The rapid growth of digital technology and infrastructure offers significant opportunities for entrepreneurs, helping to optimize the value chain and increase flexibility in addressing challenges and spotting opportunities (Autio et al., 2018). Digital technology also facilitates risk sharing and collaborative research and development (Belitski et al., 2023).

Entrepreneurs with advanced digital skills have a significant advantage in navigating market crises and unexpected events, such as COVID-19, compared to relying solely on traditional technology (Blichfeldt & Faullant, 2021). Digital capabilities require flexible, accessible, and practical knowledge, whereas industry-specific technologies often take a significant amount of time to learn and implement.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/d7679678426

Platforms like Amazon clearly show the potential of digitalization, offering tools for entrepreneurs to create innovative businesses, from product search to personalized delivery. Digital capabilities not only promote entrepreneurship but also make it easier to access resources, helping women entrepreneurs respond quickly to consumer demand and succeed in the digital world. Based on the above arguments, the research hypothesis is proposed as follows:

H2: Digital entrepreneurial capabilities have a positive influence on digital entrepreneurship.

Rangaswamy et al. (2022) argue that digital consumer behavior is a key factor in digital entrepreneurship. Digital consumers are people who use mobile devices or shop online, making decision-making easier. In the context of rapidly changing consumer preferences, entrepreneurs need to be agile in monitoring and seizing opportunities to develop suitable products or services. Hoyer et al. (2020) point out that digital technologies such as IoT, VR, AR, virtual assistants, chatbots, and robots have transformed the way consumers interact with brands and products. Today, the shift from traditional to online shopping, along with the emphasis on brand value and digital experiences, creates new opportunities for entrepreneurs.

Consumers today showcase their identity through social media and participate in digital platforms (Rogova & Matta, 2023). Social media feedback and online reviews not only help build a reputation but also directly affect businesses. Successful entrepreneurs know how to utilize this feedback to enhance products, adopt new technologies such as IoT or augmented reality, quickly respond to market needs, and maintain a competitive edge. Based on the above arguments, the research hypothesis is proposed as follows:

H3: Digital consumer behavior has a positive influence on digital entrepreneurship.

Nzembayie et al. (2019) describe digital infrastructure as a system of tools and platforms that support communication, collaboration, and information processing, thereby promoting the development of entrepreneurs in the digital environment. According to Rodrigues and Franco (2021), this infrastructure includes affordable, efficient, and competitive communication tools, such as low-cost internet, ICT technology, broadband services, cloud computing, and digital payment systems. These are key factors that help digital entrepreneurs create sustainable value. Leimstoll et al. (2018) and Quyet2024) highlight that e-business not only enables transparent and open communication but also helps entrepreneurs better understand various aspects of their businesses and projects.

Simultaneously, digital infrastructure is viewed as a platform that enables companies to connect, scale, innovate, and respond flexibly to customer needs. This provides a competitive edge by allowing differentiation. For women entrepreneurs specifically, a strong digital infrastructure, including high-speed internet, cloud services, digital payment systems, and cybersecurity measures, reduces barriers to entry, safeguards data, improves performance, and boosts competitiveness in the digital era. This creates opportunities for them to adopt innovative business models, serve global markets, and support sustainable development. Based on the above arguments, the research hypothesis is proposed as follows:

H4: Digital infrastructure has a positive influence on digital entrepreneurship.

Rodrigues and Franco (2021) highlight that digital development and innovation are closely linked, requiring governments to focus on digitalization, transformation, and global integration strategies. Stable and effective support policies, such as tax incentives and training programs, can lower barriers and encourage digital entrepreneurship. Many governments have introduced various forms of support such as grants, incubators, accelerators, and regulatory assistance (Mankevich & Holmström, 2016). Incubation ecosystems not only offer valuable information but also foster new digital ventures (Mohamed et al., 2024). Living Labs play a crucial role in supporting digital businesses from initial ideas to practical management (Le et al., 2018). Numerous researchers highlight (e.g., Jiang et al., 2021; Montero & Parga, 2023) that proper government regulations on digital technology can encourage innovation and economic growth, while ineffective policies can impede progress.

Collaboration among the government, private sector, and stakeholders is essential to sustain and expand digital entrepreneurship. Based on the above arguments, the research hypothesis is proposed as follows:

H5: Government policies have a positive influence on digital entrepreneurship.

Figure 1 shows the analytical framework as follows:

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2025 Volume 13 Number 2 (December)
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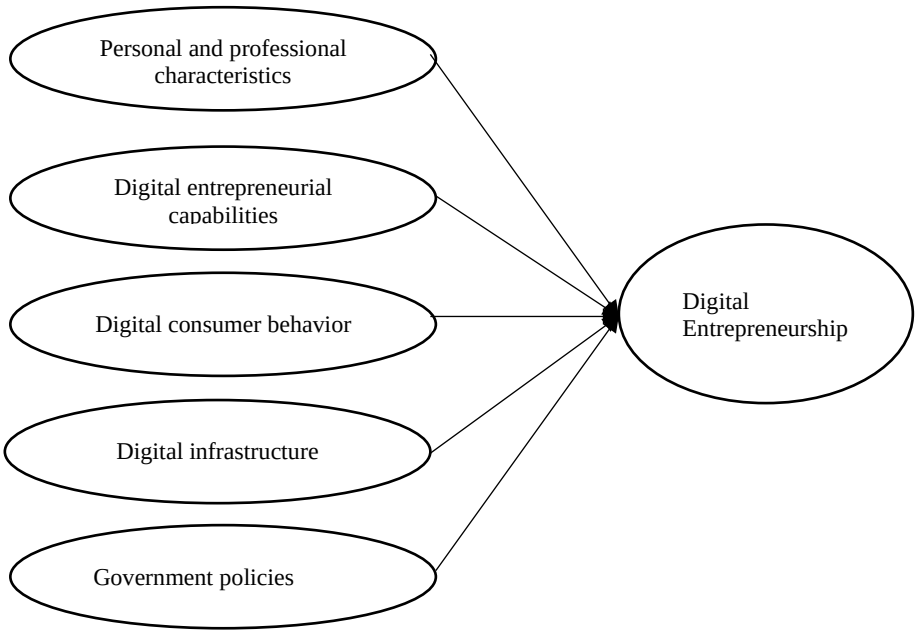


Figure 1. Analytical framework

Source: Recommended by the author

3. Methodology

According to Hair et al. (2010), the minimum sample size for EFA is 50, preferably 100 or more. A ratio of observations to an analytical variable of 5:1 or 10:1 is ideal. The study used a 10:1 ratio, so the minimum sample size would be 250. The author used a purposive non-probability sampling method to ensure the data's representativeness and reliability. The target population consisted of women entrepreneurs involved in digital business activities in Vietnam, specifically individuals with relevant knowledge and practical experience directly related to the research topic. A total of 800 questionnaires were distributed, and 527 valid responses were collected through three main channels: (1) direct distribution of questionnaires at networking events and digital start-up conferences organized by women entrepreneurship support organizations; (2) telephone interviews with participants who had limited availability; and (3) email distribution, with the support of women entrepreneur associations, start-up communities, and digital business networks in Vietnam. The study was conducted in January 2025. The respondents' participation was voluntary. The study used a 5-level Likert scale to collect data. After collecting the data, the author assessed the reliability of the data through the Cronbach's Alpha coefficient. Then, using the exploratory factor analysis (EFA) method to find out the observed variables that are significant and correlated with each other. Finally, the multivariate regression model is employed to test research hypotheses. The measurement scales used in this study were adapted from earlier research. The scale for personal and professional characteristics includes five items taken from Frese and Gielnik (2014). The four-item scale for digital entrepreneurial capabilities was adapted from Autio et al. (2018). Digital consumer behavior is assessed using five items based on the work of Rangaswamy et al. (2022). Digital infrastructure comprises four items adapted from Nzembayie et al. (2019). Government policies are evaluated with four items from Rodrigues and Franco (2021), while digital entrepreneurship is measured with three items adapted from Belitski et al. (2023).

4. Research results

4.1. Reliability test

According to Nunnally and Bernstein (1994), a scale that is accepted and well evaluated must meet two conditions: Cronbach's Alpha coefficient of the entire scale greater than 0.6, and Corrected Item-Total Correlation coefficient greater than 0.3. The results of the analysis in Table 1 show that the scale achieves the reliability recommended by Nunnally and Bernstein (1994).

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/d7679678426

Table 1. Cronbach's Alpha

Scales	Sign	Corrected Item-Total Correlation	Cronbach's Alpha
Personal and professional characteristics	PPC		0.837
- I am persistent and don't give up easily when facing challenges.	PPC1	0.707	
- I can effectively plan and organize tasks.	PPC2	0.693	
- I proactively pursue new business opportunities.	PPC3	0.739	
- I possess strong problem-solving skills in a business setting.	PPC4	0.716	
- I have extensive expertise in my field of work.	PPC5	0.700	
Digital entrepreneurial capabilities	DEC		0.783
- I can leverage digital technologies to grow my business.	DEC1	0.721	
- I understand how to incorporate digital tools into my business strategy.	DEC2	0.682	
- I have data analytics skills to inform business decisions.	DEC3	0.600	
- I can quickly adapt to emerging technology trends.	DEC4	0.621	
Digital consumer behavior	DCB		0.822
- I often shop or use services online.	DCB1	0.572	
- I look for product information on digital platforms before buying.	DCB2	0.637	
- I trust online reviews and feedback from other users.	DCB3	0.666	
- I frequently share my shopping experiences on social media.	DCB4	0.619	
- I use mobile devices to interact with businesses.	DCB5	0.701	
Digital infrastructure	DI		0.817
- I have reliable, high-speed internet access.	DI1	0.718	
- I possess the necessary technological devices for business operations.	DI2	0.729	
- Technical support services are readily available in my area.	DI3	0.710	
- I can seamlessly integrate new technologies into my business activities.	DI4	0.734	
Government policies	GP		0.808
- The government offers valuable support for digital entrepreneurship.	GP1	0.715	
- Legal policies are favorable for launching digital businesses.	GP2	0.672	
- I have access to government innovation support programs.	GP3	0.613	
- There are numerous opportunities to obtain funding or capital from the government.	GP4	0.620	
Digital entrepreneurship	DE		0.831
- I am currently involved in or planning to pursue digital entrepreneurship.	DE1	0.714	
- I believe digital entrepreneurship is my career path.	DE2	0.690	
- I actively look for business opportunities in the digital space.	DE3	0.658	

Source: Data processing results from SPSS26

4.2. Exploratory factor analysis

To meet the analysis requirements, the KMO coefficient should be between 0.5 and 1, factor loadings should be greater than 0.5, Bartlett's test should show statistical significance with a p-value less than 0.05, and the total of variance explained should be over 50 percent.

Table 2. The results of EFA

Item	Independent variables	Dependent variable
KMO	0.726	0.715
Sig. (Bartlett's test)	0.000	0.000
% of Variance	70.212	68.261
Eigenvalue	1.802	2.012

Source: Data processing results from SPSS26

The analysis of the rotation matrix reveals that five factors are extracted, which correspond to the original predictors, and the factor loadings of the variables exceed 0.5 (see Table 2 above). Therefore, no variables are eliminated.

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
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4.3. Multivariate linear regression model

The multivariate linear regression model is expressed as:

$$y = \alpha + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + ... + \beta_k x_k + \varepsilon$$

In which (x_1 = personal and professional characteristics, x_2 = digital business capabilities, x_3 = digital consumer behavior, x_4 = digital infrastructure, x_5 = government policies).

The results show that the research hypotheses have significant coefficients < 0.05. Therefore, hypotheses H1, H2, H3, H4, and H5 are accepted. Data analysis indicates that the variables (personal and professional characteristics, digital business capabilities, digital consumer behavior, digital infrastructure, government policies) positively influence digital entrepreneurship, with coefficient values of $\beta_1 = 0.367$, $\beta_2 = 0.400$, $\beta_3 = 0.318$, $\beta_4 = 0.382$, $\beta_5 = 0.415$, respectively (Table 3).

Table 3. Regression analysis

		Unstandardized coefficients		Standardized coefficients	t	Sig.	Collinearity Statistics	
		B	Standard deviation	Beta			Tolerance	VIF
1	(Constant)	0.179	0.015		2.627	0.001		
	x_1	0.356	0.030	0.367	2.392	0.023	0.615	1.802
	x_2	0.389	0.032	0.400	2.920	0.001	0.692	1.920
	x_3	0.298	0.035	0.318	2.238	0.003	0.684	1.782
	x_4	0.370	0.027	0.382	2.381	0.029	0.606	1.808
	x_5	0.401	0.032	0.415	3.203	0.002	0.639	1.901
$R^2 = 0.783$, Adjusted $R^2 = 0.777$, Sig. = 0.000, Durbin – Watson = 1.910								

Source: Data processing results from SPSS26

The study's standardized regression model is as follows:

$$DE = 0.367x_1 + 0.400x_2 + 0.318x_3 + 0.382x_4 + 0.415x_5$$

In variance analysis, the F test is used to verify the hypothesis about the suitability of the general linear regression model, thus confirming the linear relationship between the dependent variable and the entire set of independent variables. In this case, it can be concluded that the F statistic has a value of Sig. = 0.000 < 0.05, indicating that the model is entirely appropriate.

The research findings indicate that all six factors have a positive influence on the digital entrepreneurship of Vietnamese women. Specifically, based on the linear regression results presented above, government policies have the highest standardized β coefficient (0.415), suggesting they have the most significant impact on digital entrepreneurship. This is followed by digital business capabilities (β = 0.40), digital infrastructure (β = 0.38), and personal and professional characteristics (β = 0.37). Meanwhile, digital consumer behavior (β = 0.318) demonstrates the least influence on digital entrepreneurship. It is a vital preliminary step, helping women entrepreneurs turn their businesses into digital enterprises.

5. Discussion and implications

5.1. Discussion

The findings of this study provide valuable insights into the factors influencing digital entrepreneurship among Vietnamese women. The fact that all five examined factors have a positive impact suggests a complex ecosystem supporting women's involvement in digital entrepreneurship. Among these, government policies have the greatest influence on Vietnamese women's digital entrepreneurship. The results emphasize the importance of state policies in creating an environment that enables women entrepreneurs.

The results are similar to Miah et al. (2025), who suggest a comprehensive approach to support policy framework and practices, aiming to foster an inclusive digital entrepreneurship ecosystem in most developing African and Asian countries. This aligns with Vietnam's context as a transitioning economy where the government plays a central role in shaping the business landscape, especially in the digital sector. Unlike developed countries, where market forces and private investments are dominant, Vietnam still relies heavily on

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2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/d7679678426

government support policies and programs to help women access resources, training, capital, and business opportunities. Additionally, considering the challenges Vietnamese women face, such as gender prejudice, limited digital skills, or balancing work and family responsibilities, government intervention acts as a "balancing" force, establishing conditions that encourage women to participate more actively in the digital economy.

Digital business capabilities are the second most significant factor affecting digital start-ups. This highlights the crucial importance of digital skills, business insight, and technological expertise in helping women succeed and thrive in the digital entrepreneurial world. It supports earlier research that stresses the value of entrepreneurial abilities and digital literacy in improving business performance and innovative potential in the digital age.

Digital infrastructure is found to have the third-largest impact on digital entrepreneurship among Vietnamese women. Full infrastructure includes internet access, digital tools, and platforms that serve as the foundation for digital business activities. This result aligns with Vietnam's context because, over the past decade, the country has rapidly expanded its telecommunications and information technology infrastructure, with more than 70 percent of the population using the Internet and one of the highest percentages of smartphone users in Southeast Asia. It is this widespread access that has created opportunities for women, including those in rural areas, to use e-commerce, social networks, and online platforms to start businesses. However, the digital divide between urban and rural areas, as well as among different population groups, still exists, making digital infrastructure a crucial factor. If the infrastructure is improved and more evenly distributed, women's chances to engage in digital start-ups will increase significantly.

Personal and professional characteristics highlight the importance of individual attributes such as motivation, resilience, creativity, and prior experience. This finding supports existing literature (e.g., Al Omoush, 2024) that emphasizes the role of human capital in entrepreneurship, especially among women, who often face unique socio-cultural barriers in business environments.

Although digital consumer behavior showed a relatively weaker effect, its positive contributions remain important, indicating that understanding and responding to evolving consumer preferences and digital consumption patterns is essential for entrepreneurial success. This result reflects the increasing demand for customer-centric strategies in the digital economy and suggests that entrepreneurs who can effectively identify and meet consumer needs are more likely to thrive.

Overall, these findings indicate that empowering women in digital entrepreneurship needs a comprehensive approach that boosts individual skills while also improving structural and institutional support systems.

5.2. Implications

To begin with, the Vietnamese Government, in collaboration with organizations such as the Vietnam Chamber of Commerce and Industry (VCCI), the Vietnam Association of Women Entrepreneurs (VAWE), and National Innovation Centers, should initiate targeted digital capacity-building initiatives. These initiatives should encompass subsidized digital training programs for women entrepreneurs in rural and underserved regions; provision of technology adoption grants or tax incentives for women-led SMEs investing in digital platforms such as ERP, CRM, and e-commerce websites; the development of mentorship networks pairing women entrepreneurs with digital experts to facilitate practical application; and pilot programs for cross-border e-commerce training, enabling women entrepreneurs to access global markets through digital tools. Furthermore, expanding broadband internet infrastructure and mobile device access in remote areas should be a priority to promote digital inclusiveness. Giving women the tools, skills, and connectivity they need to succeed in the digital economy will not only encourage sustainable women entrepreneurship but also align with Vietnam‘s broader national strategy for digital economic integration.

Next, women entrepreneurs in Vietnam need to focus on building their information technology (IT) skills to keep pace with the digital transformation trend. Universities and specialized business education institutions play a key role by offering targeted training programs. These programs help women entrepreneurs leverage advanced technology, improving business operations both in person and online. Currently, network connectivity and

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2025 Volume 13 Number 2 (December)
http://doi.org/10.9770/d7679678426

internet access are essential, with smart and mobile devices playing a crucial role in communication, information sharing, and supporting efficient business practices, thereby boosting community value. To stay aligned with the digital transformation, women entrepreneurs in Vietnam need to strengthen their IT skills. Universities and specialized business educational institutions should take a leading role by developing and offering tailored digital skills training programs for women entrepreneurs. These programs should extend beyond basic IT literacy to include practical modules on e-commerce operations, digital marketing, cybersecurity, data analytics, and the use of AI-driven tools in business management. To ensure accessibility and effectiveness, the Ministry of Education and Training (MOET), in partnership with the Ministry of Labor, Invalids and Social Affairs (MOLISA), should require the integration of digital entrepreneurship training into existing vocational and continuing education for women-led enterprises. Furthermore, universities should create short-term certificate courses and online learning platforms in collaboration with technology companies and digital incubators.

Finally, the rapid growth of technology has created new demands for businesses, prompting women entrepreneurs in Vietnam to not only improve their skills but also expand their operations globally. In an increasingly competitive environment, women entrepreneurs must be more flexible and creative in their business strategies. Therefore, they need to review and adjust their business models to ensure they can respond to market fluctuations and stay current with new trends. Simultaneously, educational institutions and training centers in Vietnam need to develop retraining programs centered on applying technology in business management and operations, combining the “learning by doing” method to enhance efficiency. This approach not only helps women entrepreneurs meet market demand but also leverages technology to expand and strengthen their position in the digital economy, contributing to the sustainable development of businesses and the Vietnamese economy.

Conclusion

In Vietnam, women engage in business in various forms, including self-employment, small and medium-sized enterprises (SMEs), social enterprises, cooperatives, and other models. Their business potential should be directed and supported to align with their aspirations for strong growth in a modern and competitive business environment. To accomplish this, women entrepreneurs need access to expanded networks, both domestically and internationally, which will help them overcome barriers such as limited access to loans from banks and financial institutions, as well as gender biases that persist in some traditional social views. Despite facing significant challenges, Vietnamese women entrepreneurs have the potential to become a key driving force for economic development, especially when they are empowered to access and implement new technologies. This not only boosts productivity but also helps them transform their businesses into higher-value-added sectors. Promoting women’s entrepreneurship contributes to narrowing the technology gap, creating opportunities for aspiring women entrepreneurs to grow sustainably, innovate, and make meaningful contributions to the development of the Vietnamese economy in the digital age.

This study identified five factors that influence women’s digital entrepreneurial intention in an emerging economy like Vietnam, including personal and professional characteristics, digital entrepreneurial skills, digital consumer behavior, digital infrastructure, digital interactions, and government policies. The findings contribute to the empirical evidence on the factors driving digital entrepreneurship among women, a relatively new and understudied topic in developing countries. The novelty of the research lies in the combined analysis of technology, behavior, and policy contexts to provide a comprehensive understanding of women’s digital entrepreneurial activities, thus expanding existing theoretical frameworks in entrepreneurship and digital transformation.

However, the study still has some limitations. First, the data collected within Vietnam may not fully represent the cultural, economic, and digital transformation differences of other emerging countries. Second, the cross-sectional research design does not allow for assessing changes in digital entrepreneurship intentions over time. Third, measurement factors are primarily self-reported, which may be influenced by cognitive bias. Therefore, future studies could expand the survey to include many emerging countries for comparative purposes; employ a longitudinal research design to track fluctuations in digital start-up intentions; or incorporate in-depth qualitative methods to gain a deeper understanding of women's motivations, barriers, and real-world experiences

in digital entrepreneurship. These suggestions will help clarify the nature of the influencing factors and improve the generalizability of the research findings.

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