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THE GENDER-SUSTAINABILITY NEXUS IN THE EUROPEAN CONTEXT: A PANEL DATA ANALYSIS*

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Abstract. This study analyses the impact of female leadership on sustainable development indicators and environmental efficiency across 28 European countries (EU-27 and Türkiye) over the period 2015–2023. Utilising panel data and fixed-effects econometric models, the relationship between female representation in legislative bodies, government, and corporate governance (boards and executive positions) is investigated in relation to the Sustainable Development Goals Index (SDG Index) and carbon dioxide (CO₂) emissions. The results confirm a statistically significant positive correlation between the proportion of women in national parliaments and the achievement of systemic sustainability goals, thereby supporting theoretical premises regarding the more pronounced social and ethical orientation of female leaders. With regard to the environmental footprint, the role of corporate gender diversity in mitigating emissions is identified, although this effect remains strongly mediated by macroeconomic factors and the national energy profile. The observed *glass cliff* phenomenon – whereby women are appointed to senior leadership roles during periods of crisis or downturn – among female executives underscores the necessity for a more in-depth analysis of the institutional context in which leadership is exercised. The scientific novelty lies in the integrated examination of political and corporate power as determinants of sustainability amidst systemic crises. These findings have direct applicability to the formulation of public policies and Environmental, Social, and Governance (ESG) strategies, demonstrating that gender diversity is a critical instrument for accelerating the green transition and achieving socio-economic stability in Europe.

Keywords: female leadership; sustainable development goals; SDG performance; SDGs; carbon emissions; corporate governance; ESG; European Union

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Additional disciplines: political sciences; sociology; ecology and environment; environmental engineering

1. Introduction

In the contemporary era of global environmental and social transformations, the question of managerial elites' capacity to generate sustainable solutions is of paramount relevance. The adoption of the 2030 Agenda and the Sustainable Development Goals (SDGs) by the United Nations established a new framework wherein achieving gender equality (SDG 5) is viewed not merely as a fundamental human right, but as a prerequisite for the

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realisation of the remaining 16 goals (UN Women, n.d.). Nevertheless, data indicate that the path towards parity in political representation remains protracted, necessitating a more profound analysis of the contribution of female leaders to national sustainability levels (UN Women, 2024; Joint Research Centre, 2025).

The theoretical foundation of this study is premised on the concept that women in senior leadership positions introduce a distinct leadership style, frequently oriented towards the long-term well-being of the community and ethical governance (Mirza et al., 2024). In the political sphere, the heightened presence of women in legislative bodies is associated with a more substantial commitment to the social pillars of sustainable development, including healthcare, education, and social protection (Toukabri & Jilani, 2023; Tarkovska et al., 2023). Research suggests that these leadership characteristics are essential for enhancing national performance regarding the SDG Index (World Bank, 2024; Roca et al., 2024).

Within the corporate sphere, the debate focuses on the role of women in governing bodies (boards) and executive positions regarding the integration of Environmental, Social, and Governance (ESG) factors (EcoActive Tech, 2024; Thawornlamlert et al., 2025; Hargrave et al., 2026). Critical mass theory posits that when female presence in corporate governance reaches a certain threshold, a qualitative shift occurs in organisational priorities – transitioning from a focus on short-term profit to strategies for decarbonisation and the reduction of carbon footprints (Yudiani et al., 2024; Kray et al., 2025; Pecher et al., 2025). This is particularly relevant in the context of the European Union’s new regulatory framework concerning ESG reporting and corporate sustainability (Lindstrand et al., 2024; CFA Institute, 2024).

The present study aims to bridge a gap in the literature by comparing 28 European countries (EU-27 and Türkiye) over the period 2015–2023. Employing a rigorous econometric methodology, the work investigates how variations in female representation in parliament, government, and the corporate sector correlate with national levels of the SDG Index and CO₂ emissions (Elder & Grünewald, 2025; Piqueiras & Luoma-aho, 2025; Ozcelik et al., 2025). In a period of systemic crises, leadership that prioritises inclusivity and resilience emerges as a key factor for the sustainable future of the European region (Telleria, 2024; Ali et al., 2025).

2. Literature review

Theoretical foundations of female leadership

Over the last decade, the global landscape of political leadership has undergone a visible, albeit uneven, transformation. The nexus between gender equality and sustainable development is fundamental, with female participation identified as a critical accelerator for the achievement of the SDGs and specifically Goal 5 (UN Women, n.d.). Nevertheless, progress remains slow and frequently fragmented. An analysis of World Bank data for the period 2015–2024 demonstrates a steady yet gradual upward trend in the proportion of women in national parliaments, with global figures still struggling to surpass the one-third threshold required to achieve a critical mass (World Bank, 2024).

By late 2025, data from the Inter-Parliamentary Union (IPU) revealed that, whilst certain nations have already attained or are approaching parity, on a global scale, women continue to be underrepresented at the highest levels of decision-making (Inter-Parliamentary Union, 2025). Empirical evidence indicates that only a small percentage of countries have female heads of state or government, and the pace of change is such that, should current rates persist, full gender equality in the highest echelons of power will not be achieved within the next 130 years (UN Women, 2024). This underscores the systemic barriers that continue to impede women’s access to leadership positions, despite the proven benefits of their participation.

Within the context of the European Union, the situation exhibits greater dynamism; however, the trajectory towards full equality remains fraught with challenges. Reports by the Joint Research Centre (JRC) of the European Commission acknowledge improvements in female political representation yet emphasise that *the road to parity remains long*, even within the EU (Joint Research Centre, 2025). Data confirm that, despite the existence of progressive policies and quotas in certain Member States, structural inequalities persist. Women remain a minority in key spheres of economic and political influence, a factor which directly impinges upon the velocity of achieving sustainability goals (UN Women, 2024; Joint Research Centre, 2025).

The evolution in the understanding of female representation is characterised by the concept of *critical mass*, shifting the locus of analysis from purely quantitative dimensions to the qualitative transformation of policies (Amo-Navas et al., 2025). Classical and contemporary interpretations of the theory, including the critiques by Sarah and Mona (2008), underscore that the mere presence of women (*descriptive representation*) does not automatically guarantee a shift in political outcomes (*substantive representation*). To overcome the effects of *tokenism* – in which women serve merely as a symbolic presence – it is necessary to reach a threshold that enables the minority to exert a tangible impact on group dynamics and decision-making processes.

Within the corporate context, empirical research unequivocally supports the proposition that attaining a critical mass – frequently defined as a minimum of three women on the board of directors – is a decisive determinant of the enhancement of Corporate Social Responsibility (CSR) (Boukattaya & Omri, 2021). Once women cease to function as isolated *tokens* and constitute a substantive cohort, their efficacy in enforcing ethical standards and socially oriented strategies is amplified, thereby directly elevating the CSR ratings of organisations (Toukabri & Jilani, 2023). Furthermore, the existence of a critical mass of female directors serves as a corrective mechanism against practices of *ESG decoupling* – the divergence between declared ESG policies and actual corporate conduct – thereby ensuring heightened transparency and accountability (Boukattaya & Omri, 2021; Roca et al., 2024).

The nexus between critical mass and environmental sustainability is particularly pronounced within the domains of innovation and carbon footprint management. Contemporary analyses indicate that boards characterised by balanced gender representation are significantly more inclined to initiate and fund eco-innovations, with female leaders introducing diverse cognitive perspectives and a lower tolerance for environmental risks (Mirza et al., 2024). This finding is corroborated by specific studies focusing on carbon efficiency, which demonstrate that, subsequent to surpassing a specific threshold of representation, female directors successfully enforce policies for carbon emission reduction, transforming sustainability from a peripheral concern into a strategic priority (Tarkovska et al., 2023).

Social role theory has traditionally distinguished between two primary modes of behaviour: *agentic*, characterised by assertiveness, competitiveness, and task orientation, stereotypically ascribed to men; and *communal*, associated with care, cooperation, and empathy, typically linked to women (Boukattaya & Omri, 2021). However, contemporary research nuances this dichotomy, demonstrating that female leaders increasingly exhibit flexibility by combining decisiveness with high emotional intelligence. This hybrid approach proves pivotal for effective management within the modern dynamic environment, enabling women to transcend traditional biases and construct more resilient organisational cultures (Kray et al., 2025; Ali et al., 2025).

In the context of corporate governance and industry, the communal style of women manifests itself through a pronounced focus on employee and stakeholder well-being. Empirical data indicate that women in managerial roles are more inclined to foster an inclusive environment and prioritise ethical behaviour over short-term financial performance (Amo-Navas et al., 2025). This leadership style not only enhances the internal organisational climate but also establishes the prerequisites for the more successful implementation of sustainability strategies, as it necessitates the balancing of diverse and frequently conflicting interests (Yudiani et al., 2024; Thawornlamlert et al., 2025).

Furthermore, the specific approach of women to decision-making frequently entails a more comprehensive risk assessment and broader consultation, thereby mitigating the likelihood of impulsive or hazardously aggressive corporate manoeuvres. The literature underscores that this *transformational* leadership model is particularly effective in crisis management and innovation deployment, as female leaders successfully transform their teams through personal example and the fostering of collective responsibility – attributes that are fundamental to achieving the SDGs (Hargrave et al., 2026).

The sustainable development paradigm and the SDGs

The UN Agenda 2030 framework constitutes a fundamental paradigm shift in global development, transitioning from sectoral to systems thinking. In contrast to its predecessors, the SDGs are not isolated objectives but an integrated network of indivisible priorities, wherein social inclusion, economic growth, and environmental protection are mutually interdependent (Chenary et al., 2024; Thammaraksa et al., 2024). Contemporary futures studies underscore that the realisation of this ambitious agenda necessitates a holistic approach that regards planetary boundaries and human well-being as interconnected vessels rather than competing interests (Telleria, 2024; Sofiyah et al., 2025).

Occupying a central position within the scientific discourse is the concept of synergies and trade-offs between individual goals. Empirical research in the fields of the circular economy and resource management demonstrates that environmental measures (such as those concerning climate and clean energy) exert a multiplier effect on social indicators, provided they are managed with precision (Chenary et al., 2024). For instance, the transition towards a low-carbon economy possesses the potential to stimulate innovation and employment; however, it mandates meticulous planning to preclude the exacerbation of inequalities (Rieiro-García et al., 2023; Elder & Grünewald, 2025). In particular, at the level of urban planning and regional development, the nexus between social infrastructure and environmental sustainability is critical – sustainable cities (SDG 11) cannot function in the absence of robust institutions and social cohesion (García et al., 2025).

Notwithstanding the theoretical consensus regarding interconnectedness, practical implementation encounters challenges pertaining to communication and the corporate integration of the goals (Bose et al., 2023). The literature indicates that, to ensure efficacy, the framework must be translated into the language of business and local communities, whilst avoiding the fragmented treatment of issues (Thammaraksa et al., 2024). The role of technology and digitalisation emerges as a pivotal factor in accelerating this process, provided that they serve to bridge social deficits rather than merely fuelling technological optimism (Lindstrand et al., 2024). Ultimately, the success of Agenda 2030 is contingent upon the capacity of leaders to manage the complex interactions between economic aspirations and socio-ecological realities, thereby minimising conflicts between them (García-Sánchez et al., 2023; Piqueiras & Luoma-aho, 2025).

The European Union is establishing itself as a global leader in the regulatory institutionalisation of sustainable development, transitioning from voluntary initiatives to a stringent legislative framework. This process is driven by the ambition of the European Green Deal to reorient capital flows towards sustainable investments. The foundation of this ecosystem is constituted by three interconnected pillars: the Sustainable Finance Disclosure Regulation (SFDR), the EU Taxonomy Regulation, and the Corporate Sustainability Reporting Directive (CSRD). This complex architecture aims to eliminate *greenwashing* and establish a unified language for the classification of economic activities, which is of critical importance for investors and asset managers (The Global Legal Post, n.d.; CFA Institute, 2024; Cojocaru et al., 2025).

A pivotal element within this regulatory transformation is the introduction of CSRD and the accompanying European Sustainability Reporting Standards (ESRS), which fundamentally alter the reporting obligations of enterprises (Cojocaru et al., 2025). Central to these contemporary measurement methodologies is the concept of *double materiality*. This approach necessitates a bidirectional assessment of sustainability: financial materiality (pertaining to how external climate risks impinge upon enterprise value) and impact materiality (concerning how the company's own operations affect society and the environment). To operationalise this, the framework mandates the utilisation of precise quantitative metrics, such as Key Performance Indicators (KPIs), across the entire product and service life cycle (Bose et al., 2023). Ultimately, this expansion of scope transforms ESG data from a mere marketing instrument into a mandatory, auditable asset, commensurate in importance with traditional financial statements (CFA Institute, 2024; EcoActive Tech, 2024; Lexology, 2024; The Global Legal Post, n.d.).

Regulatory pressure is further intensified by the Corporate Sustainability Due Diligence Directive (CS3D), which extends corporate liability beyond internal operations to encompass the entire value chain. This legislation mandates large enterprises to identify and mitigate adverse impacts on human rights and the environment, including those occurring within their supply networks. Legal analyses indicate that this

establishes a new standard for corporate conduct, wherein risk management is no longer an isolated internal function but necessitates profound oversight and control of global supply chains (The Global Legal Post, n.d.; Lexology, 2024).

From both academic and practical perspectives, the integration of these regulations constitutes a formidable challenge, yet simultaneously offers a strategic avenue for innovation. Contemporary scholarship indicates that enterprises successfully embedding ESG principles within their business models exhibit enhanced operational efficiency and superior resilience to market volatility. Nevertheless, this transition necessitates substantial resources for data collection and verification, alongside a fundamental paradigm shift in managerial culture (Ionaşcu et al., 2025; Pecher et al., 2025). Empirical data from 2025 corroborate that, whilst the regulatory burden is substantial, it functions as a catalyst for the deployment of clean technologies and circular models, thereby directly linking environmental performance with the long-term economic viability of enterprises (Ozcelik et al., 2025).

The operationalisation of the sustainable development concept necessitates a transition from abstract political objectives to concrete, measurable indicators. Within the European Union, this process is undergoing a fundamental transformation via the introduction of the European Sustainability Reporting Standards (ESRS), which aim to unify the hitherto fragmented methodologies. The primary challenge regarding measurement lies in the multidimensionality of sustainability, which encompasses heterogeneous variables – ranging from carbon emissions to social inclusion. To surmount this complexity, the scientific community and regulators increasingly rely upon composite indices and aggregated data, which facilitate comparative analysis and the assessment of progress relative to planetary boundaries (EcoActive Tech, 2024; Lexology, 2024).

Notwithstanding the progress in standardisation facilitated by the EU Taxonomy Regulation, which furnishes a classification system for *green* activities, the measurement of the social pillar of sustainability remains a formidable challenge. Whilst environmental indicators (such as greenhouse gas emissions) are readily quantifiable, social and governance aspects frequently necessitate more complex proxy variables. Academic scholarship underscores the imperative for integrated models capable of encompassing the synergies between technological innovation and social well-being, thereby eschewing the reductive treatment of data. Consequently, effective measurement depends on the ability to aggregate these disparate data streams into unified indices that serve as a robust foundation for strategic decision-making (Ionaşcu et al., 2025; Ozcelik et al., 2025; Pecher et al., 2025).

The nexus of gender and sustainability

The nexus between female participation in governance and enhanced sustainability metrics is not coincidental; rather, it is underpinned by several key theoretical mechanisms that elucidate the transformation of corporate and political strategies. The primary and most frequently cited mechanism is *Cognitive Diversity Theory*. According to this theory, heterogeneous groups possess a broader spectrum of perspectives, knowledge, and problem-solving heuristics compared to homogeneous ones (Amo-Navas et al., 2025). Empirical evidence indicates that the inclusion of women on boards disrupts *groupthink* and stimulates *green* innovation (Babiker et al., 2025), as women frequently introduce unique experiences and heightened sensitivity to non-financial risks, a factor critical for the identification of environmental opportunities (Tarkovska et al., 2023; Mirza et al., 2024).

The second mechanism draws upon *Stakeholder Theory*. Whilst traditional governance models frequently prioritise shareholders, the literature reveals that female leaders are more inclined to perceive the organisation as an integral component of a broader social ecosystem (Bouaddi et al., 2023; Yorke et al., 2023). This mechanism is intrinsically linked to the *communal* leadership style, which fosters empathy and long-term community stewardship. Research corroborates that boards characterised by balanced gender participation are more active in CSR and more effectively reconcile economic objectives with the needs of employees, local communities, and the environment (Toukabri & Jilani, 2023; Yudiani et al., 2024).

The third substantive mechanism pertains to ethics and the management of reputational risk. Female executives demonstrate a lower tolerance for unethical business practices and a heightened propensity for transparency (Babiker et al., 2025). This mechanism functions as a protective shield against *greenwashing*, as diverse teams exhibit greater rigour regarding accountability and regulatory compliance. Analyses indicate that this elevated ethical standard not only mitigates the likelihood of environmental litigation but also transforms sustainability from a peripheral public relations activity into a core strategic objective (Roca et al., 2024; Thawornlamert et al., 2025; Ali et al., 2025).

The accumulated body of empirical research in recent years provides compelling evidence of a positive correlation between gender diversity within governing bodies and CSR performance (Yorke et al., 2023). Analyses of large panel datasets reveal that enterprises with a higher proportion of women on boards of directors consistently secure superior ESG ratings (Bouaddi et al., 2023). This is attributed to the fact that gender-diverse boards are more effective in the oversight of managerial strategies and more frequently initiate the establishment of specialised sustainability committees, which institutionalise the firm's CSR commitments (Toukabri & Jilani, 2023; Yudianti et al., 2024).

Another substantive aspect of the empirical evidence concerns the impact of women on the quality and transparency of non-financial disclosure. The literature establishes that the presence of female directors significantly attenuates information asymmetry between the entity and its stakeholders (Yorke et al., 2023). Empirical data indicate that such boards exhibit a higher propensity to voluntarily disclose information on carbon footprints and social impact, whilst simultaneously serving as a deterrent to reporting manipulation practices (greenwashing). This validates the thesis that gender diversity augments investor confidence via stricter adherence to ethical accountability standards (Roca et al., 2024; Thawornlamert et al., 2025).

Beyond accountability, the data reveal a direct correlation between the feminisation of senior management and investment in eco-innovations. Research indicates that firms with a critical mass of women in governance do not merely comply with regulations but also proactively invest in green technologies and circular business models to gain competitive advantage (Babiker et al., 2025). This trend is particularly evident in energy-intensive industries, where female board representation correlates with the accelerated adoption of decarbonisation strategies and more effective management of environmental risks (Mirza et al., 2024; Tarkovska et al., 2023).

The nexus between female political empowerment and national environmental performance constitutes a subject of burgeoning academic scrutiny. Macroeconomic analyses and reports by international bodies such as the UN and the World Bank indicate the existence of a positive correlation between the proportion of women in national parliaments and the enactment of more stringent climate legislation. Nations with higher levels of female political leadership demonstrate a greater propensity to ratify international environmental treaties and to accelerate the integration of sustainability principles into national development strategies. This corroborates the thesis that female legislators frequently function as agents of change, prioritising long-term societal well-being over short-term political dividends (UN Women, n.d.; World Bank, 2024).

From a theoretical perspective, this phenomenon is explicated via the concept of substantive representation. According to this framework, an increase in the number of women in politics induces a shift in the agenda of legislative bodies, allocating greater attention to issues traditionally associated with quality of life, health, and the environment. Within the context of the European Union, data from the JRC support the observation that balanced political participation constitutes a critical prerequisite for the successful realisation of the Green Deal, as female leaders are more inclined to endorse policies ensuring the socially equitable distribution of the costs associated with the green transition (Joint Research Centre, 2025).

Empirical observations concerning the implementation of the SDGs indicate that political empowerment (SDG 5) exerts a synergistic effect upon goals pertaining to climate and resources. Analyses reveal that in nations where women possess substantive decision-making power, lower per capita carbon emissions and more efficacious management of natural resources are observed. This effect becomes statistically significant once representation transcends specific thresholds, enabling female politicians not merely to participate in the

discourse but to formulate and enforce environmental policies that might otherwise be disregarded (UN Women, n.d.; Inter-Parliamentary Union, 2025).

Based on the presented theoretical frameworks and the identified dependencies in the literature, the present study focuses on elucidating the relationship between female leadership and the achievement of sustainability goals within the European context. The logical extension of the analysed framework facilitates the formulation of the following research hypotheses:

Hypothesis 1 (H_1): The presence of a higher proportion of women in senior leadership positions (political and corporate) is positively associated with the overall level of a country's sustainable development, as measured by the SDG Index. This hypothesis is grounded in Social Role Theory and Ecofeminism. According to these perspectives, women are inclined to exhibit a more pronounced *ethical leadership style*, oriented towards the long-term well-being of the community rather than solely towards short-term gains. In the political sphere, women frequently endorse policies in the domains of social inclusion, education, and healthcare, which constitute fundamental pillars of the SDGs.

Hypothesis 2 (H_2): Higher female representation in corporate boards and executive positions leads to lower levels of carbon emissions per capita. The formulated hypothesis rests upon Critical Mass Theory and Stakeholder Theory. When women attain a critical mass in corporate governance (boards and CEOs), they shift corporate strategy from a purely shareholder-centric (profit-only) approach to one that accounts for the interests of society and the environment. Research indicates that female leaders are more prone to enforcing investments in *green innovations* and stricter pollution controls, which manifests at the national level as a reduction in the total carbon footprint (CO₂ emissions).

Before proceeding with the methodological framework, it is important to acknowledge a specific boundary condition of this study. While the SDG Index and levels of carbon emissions per capita provide robust, aggregated metrics for macro-level analysis, they may not reflect the entire spectrum of SDG facets and nuanced socio-environmental dynamics. The different approaches towards measuring SDG implementation and corporate sustainability remain a fertile ground for future research among scholars interested in this multidimensional topic.

3. Methodology

The present study employs a quantitative approach grounded in panel data analysis to investigate the empirical relationship between female leadership and the attainment of sustainability goals within the European context. The selection of this methodology is predicated on the necessity to control for both cross-country heterogeneity and dynamic temporal variations.

Sample and data sources

The empirical analysis encompasses the 27 Member States of the European Union (EU-27), with the sample augmented to include Türkiye. The inclusion of Türkiye is justified by its status as a key candidate country for accession and a strategic economic partner within the framework of the Customs Union with the EU. This enables the study to transcend the administrative boundaries of the Union and provides a comparative analysis within the broader European context.

A balanced panel covering the period 2015–2023 was utilised. The initial year coincides with the adoption of Agenda 2030, whilst 2023 was selected as the endpoint, representing the final year for which complete and validated data were available for all examined indicators and countries at the time of the research. Data were extracted from the official database of Eurostat (2026), thereby ensuring full methodological comparability.

Definition of variables

The model incorporates three distinct categories of variables: *dependent* (sustainability performance metrics), *independent* (female leadership indicators), and *control* (economic and social factors).

A. Dependent variables (Sustainability performance)

To measure overall sustainability attainment, the study employs the SDG Index Score. Developed by the UN Sustainable Development Solutions Network (SDSN), this composite indicator evaluates the performance of each country on a scale ranging from 0 (lowest performance) to 100 (optimum performance) across all 17 SDGs. The utilisation of an aggregated index facilitates a holistic assessment that balances the economic, social, and environmental dimensions of sustainable development, thereby eschewing sectoral fragmentation.

To ensure the robustness of the results and to mitigate potential endogeneity concerns (given that gender equality indicators constitute a component of SDG 5), the analysis employs two complementary metrics:

1. *SDG Index Score* (SDG_Index): A composite indicator evaluating performance across all 17 UN goals. This metric permits a holistic assessment, equilibrating economic, social, and environmental dimensions;
2. *Annual CO₂ emissions* (tonnes per capita): Carbon dioxide emissions per capita. This indicator provides a scientifically validated metric for the environmental footprint and facilitates the testing of hypotheses within the context of decarbonisation.

B. Independent variables (Female leadership)

The primary focus of the study lies in the variables representing gender diversity within decision-making processes. The research scrutinises leadership across three pivotal loci of power, aiming to evaluate and compare the relative weight of legislative, executive, and corporate authority:

1. *Legislative Power* (Women_Parl %): Proportion of seats held by women in national parliaments.
2. *Political Executive Power* (Women_Gov %): Proportion of women in senior government positions (senior ministers).
3. *Corporate Governance* (Women_Board %): Proportion of women board members in the largest listed companies. This metric reflects the strategic and supervisory functions within the business sector.
4. *Corporate Management* (Women_Exc %): Proportion of women executives in the largest listed companies. This metric reflects operational authority within the business sector.

C. Control variables

To isolate the net effect of female leadership, the model controls for the following macroeconomic factors, which are empirically established determinants of sustainability:

- *Logarithm of GDP per capita* (LnGDP): The natural logarithm of GDP per capita is utilised to correct for distributional skewness and to measure economic elasticity relative to sustainability.
- *R&D Expenditure* (RD_Exp) (% of GDP): Controls for national innovation capacity.
- *Human Capital Quality* (Edu_Level): Tertiary educational attainment (%). The analysis employs the 25–34 age group, which constitutes the official EU headline indicator for monitoring educational targets. This selection is predicated on the fact that this younger cohort most accurately reflects the current qualification potential of the workforce and recent investments in human capital, in contrast to the general population, which encompasses historical legacy effects.

Empirical strategy and econometric model

To empirically test the formulated hypotheses, a Fixed Effects (FE) regression model is employed. This estimation strategy is preferred over Ordinary Least Squares (OLS) and Random Effects (RE) approaches, as it effectively controls for unobserved time-invariant country-specific heterogeneity (such as cultural norms, historical context, and geography). The selection of the FE specification is theoretically grounded in the anticipated correlation between these unobserved country effects and the independent regressors. However, for comparative purposes and to establish a baseline, pooled OLS regressions are initially estimated, followed by the rigorous FE models to isolate the net impact. The baseline regression equation is specified as follows:

$$Y_{it} = \beta_0 + \beta_1 \text{FemLead}_{it} + \beta_2 \text{Controls}_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

Where:

- Y_{it} denotes the value of the dependent sustainability variable for country i in year t .
- FemLead_{it} represents the vector of female leadership variables (Parliament/Boards).
- Controls_{it} is the vector of control variables (GDP, R&D, Education).
- μ_i captures country-specific fixed effects which remain constant over time.
- λ_t denotes time fixed effects, absorbing common EU-wide shocks.
- ε_{it} is the stochastic error term.

To ensure the reliability of the results, the models are subjected to rigorous diagnostic testing. The Variance Inflation Factor (VIF) test is applied to identify potential multicollinearity, ensuring that values remain below the critical threshold of 5.0. Furthermore, the Breusch-Pagan test is conducted to detect heteroscedasticity in the residuals, thereby ensuring the accurate computation of standard errors and significance levels.

The validity of the econometric estimates is ascertained through a comprehensive series of diagnostic procedures, comprising tests for multicollinearity and heteroscedasticity. The employment of the FE specification is methodologically justified to mitigate biases arising from unobserved cross-country heterogeneity and non-constant error variance, thereby ensuring a high degree of robustness in the statistical inferences.

3. Results and discussion

The descriptive statistics presented in Table 1 furnish a systematic overview of the fundamental parameters of the studied population over the period 2015–2023, comprising a total of 252 observations. The values associated with the dependent variables elucidate essential characteristics of sustainable development within the sample. The Sustainable Development Goals Index (SDG_Index) exhibits a comparatively high mean value of 79.63 points, accompanied by a relatively low standard deviation of 3.53; this is indicative of a certain degree of convergence regarding the performance of the nations under review. Conversely, annual per capita CO₂ emissions vary across a broad spectrum – ranging from 3.02 to 16.39 tonnes – with a mean value of 6.41 tonnes. This significant dispersion in emissions reflects the heterogeneity inherent in the energy and industrial profiles of the included economies, thereby establishing the requisite statistical foundation for investigating the determinants influencing environmental outcomes.

Table 1. Descriptive statistics of indicators for female leadership, sustainable development and control variables (2015–2023)

Descriptive Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
Women_Parl %	252	10,1000000000	49,6000000000	28,691269841270	9,7389186785031
Women_Gov %	252	,0000000000	72,4000000000	29,541269841270	14,0207062006570
Women_Board %	252	4,5000000000	46,1000000000	23,642857142857	10,3774036514558
Women_Exc %	252	4,1000000000	34,8000000000	17,906349206349	6,8304771205460
SDG_Index	252	68,83	87,10	79,6314	3,52859
Annual CO ₂ emissions (per capita)	252	3,0220766	16,3886240	6,409312692	2,4816006493
Edu_Level	252	22,5000000000	63,0000000000	42,194444444444	9,1639889847402
RD_Exp	252	,4500000000	3,6400000000	1,652301587302	,8739138166215
LnGDP	252	8,81	11,59	10,1462	,62575
Valid N (listwise)	252				

Source: Authors' processing based on Eurostat data

With regard to the key independent variables, pronounced dynamics are observed in the levels of female representation across distinct power structures. The proportion of women in national parliaments averages 28.69%; the maximum value of 49.60% indicates that, within the studied period, no single country in the sample achieved full parity representation in legislative power. The highest volatility is established within the executive branch (Women_Gov %), wherein the share of female ministers ranges from 0.00% to 72.40%. The presence of zero values for this indicator, combined with the highest standard deviation (14.02), underscores that government compositions are subject to more frequent and radical alterations compared to parliamentary

representation. In the corporate sector, the data reveal a hierarchical differentiation in female representation. The mean proportion of women on corporate boards (Women_Board %) is 23.64%, which is significantly higher than their presence in top operational positions (Women_Exc %), amounting to an average of 17.91%. The latter variable records the lowest mean levels among all examined leadership indicators, which may be interpreted as an indication of the persistence of structural barriers facing women at the executive level. The range of these data provides sufficient variation for the conduct of robust correlation and regression analyses.

The control variables complement the context of the economic and social environment. The educational attainment of the population (Edu_Level) shows a mean value of 42.19%, whilst Research and Development expenditure (RD_Exp) varies from a minimum of 0.45% to 3.64% of GDP. The economic level, represented by the logarithm of GDP per capita (LnGDP), maintains a stable distribution with a mean value of 10.15. The integrated review of descriptive statistics confirms that the dataset is balanced and meets the requisite statistical requirements for the application of a Fixed Effects model, thereby permitting the precise testing of the formulated hypotheses.

The results from the Pearson correlation analysis (Table 2) reveal a complex nexus of statistically significant dependencies between the examined leadership metrics and the sustainability indicators. Primarily, a strong and positive intercorrelation is established between female representation in national parliaments, government structures, and corporate boards. The correlation coefficients between Women_Parl % and Women_Gov % ($r = 0.758$, $p < 0.01$), as well as between parliamentary representation and corporate board presence ($r = 0.742$, $p < 0.01$), suggest the existence of coherent emancipation trajectories within both the public and private sectors. In stark contrast, the share of women in executive positions (Women_Exc %) demonstrates weak or even statistically insignificant associations with the other leadership indicators, which corroborates the hypothesis regarding the distinct barriers and dynamics involved in occupying the highest operational roles.

Table 2. Pearson correlation matrix for the studied variables

		Correlations								
		Women_Parl %	Women_Gov %	Women_Board %	Women_Exc %	SDG_Index	Annual CO ₂ emissions (per capita)	Edu_Level	RD_Exp	LnGDP
Women_Parl %	Pearson Correlation	1	,758**	,742**	,016	,598**	,108	,276**	,725**	,579**
	Sig. (2-tailed)		,000	,000	,797	,000	,087	,000	,000	,000
	N	252	252	252	252	252	252	252	252	252
Women_Gov %	Pearson Correlation	,758**	1	,664**	,193**	,505**	,013	,244**	,600**	,435**
	Sig. (2-tailed)	,000		,000	,002	,000	,839	,000	,000	,000
	N	252	252	252	252	252	252	252	252	252
Women_Board %	Pearson Correlation	,742**	,664**	1	,054	,577**	-,109	,176**	,630**	,459**
	Sig. (2-tailed)	,000	,000		,393	,000	,083	,005	,000	,000
	N	252	252	252	252	252	252	252	252	252
Women_Exc %	Pearson Correlation	,016	,193**	,054	1	,159*	-,353**	,115	-,130*	-,184**
	Sig. (2-tailed)	,797	,002	,393		,011	,000	,068	,040	,003
	N	252	252	252	252	252	252	252	252	252
SDG_Index	Pearson Correlation	,598**	,505**	,577**	,159*	1	-,035	-,013	,636**	,394**
	Sig. (2-tailed)	,000	,000	,000	,011		,583	,832	,000	,000
	N	252	252	252	252	252	252	252	252	252
Annual CO ₂ emissions (per capita)	Pearson Correlation	,108	,013	-,109	-,353**	-,035	1	,181**	,179**	,435**
	Sig. (2-tailed)	,087	,839	,083	,000	,583		,004	,004	,000
	N	252	252	252	252	252	252	252	252	252
Edu_Level	Pearson Correlation	,276**	,244**	,176**	,115	-,013	,181**	1	,127*	,555**
	Sig. (2-tailed)	,000	,000	,005	,068	,832	,004		,045	,000
	N	252	252	252	252	252	252	252	252	252
RD_Exp	Pearson Correlation	,725**	,600**	,630**	-,130*	,636**	,179**	,127*	1	,551**
	Sig. (2-tailed)	,000	,000	,000	,040	,000	,004	,045		,000
	N	252	252	252	252	252	252	252	252	252
LnGDP	Pearson Correlation	,579**	,435**	,459**	-,184**	,394**	,435**	,555**	,551**	1
	Sig. (2-tailed)	,000	,000	,000	,003	,000	,000	,000	,000	
	N	252	252	252	252	252	252	252	252	252

** . Correlation is significant at the 0.01 level (2-tailed).

* . Correlation is significant at the 0.05 level (2-tailed).

Source: Authors' processing based on Eurostat data

With respect to the central dependent variable, *SDG_Index*, a significant positive correlation is observed with three of the four leadership indicators, with the connection to parliamentary representation ($r = 0.598$, $p < 0.01$) and board presence ($r = 0.577$, $p < 0.01$) being the most pronounced. These results provide preliminary validation of the theoretical expectations that higher female participation in strategic decision-making corresponds to superior levels of sustainable development. It is noteworthy that the relationship between *Women_Exc %* and the *SDG_Index*, whilst significant, is considerably weaker ($r = 0.159$, $p < 0.05$); this necessitates a more in-depth regression analysis to disentangle the direct effect from that of other macroeconomic factors.

The analysis of the environmental indicator unveils a specific and somewhat unanticipated dynamic. Whilst political and board representation do not exhibit a statistically significant linear relationship with CO_2 emissions, the share of female executives registers a moderate but highly significant inverse correlation ($r = -0.353$, $p < 0.01$). This finding is of particular salience, as it implies that female leadership at the operational business level is associated with lower carbon intensity within the economy. Concurrently, the strong positive correlations of emissions with LnGDP ($r = 0.435$, $p < 0.01$) and *Edu_Level* ($r = 0.181$, $p < 0.01$) underscore the complexity of environmental impact in developed economies, where a higher standard of living is frequently concomitant with elevated resource consumption.

The control variables – economic level (LnGDP) and investment in innovation (*RD_Exp*) – maintain stable positive correlations with the indicators of female leadership and the *SDG_Index*. The connection between Research and Development expenditure and female representation in parliament and boards is particularly pronounced, reflecting the synergy between social progress and innovation capacity. Whilst the high levels of correlation between certain independent variables justify the verification of multicollinearity via the VIF test in subsequent stages, the overall structure of the matrix confirms that the included factors capture distinct dimensions of socio-economic reality, which constitutes a prerequisite for the adequacy of the subsequent regression models.

Prior to testing the fundamental hypotheses, a verification of the diagnostic prerequisites of the models was conducted. The results from the analysis of the Variance Inflation Factor (VIF) for all independent variables are below the threshold of 4.0 (maximum VIF = 3.97), which unequivocally precludes the presence of multicollinearity and allows for the precise isolation of the effects of the various levels of female leadership. Additionally, the Breusch-Pagan test was applied to identify potential heteroscedasticity. The results for the *SDG_Index* model ($F = 24.82$, $p < 0.001$) and for the carbon emissions model ($F = 13.30$, $p < 0.001$) confirm the presence of non-constant error variance. In accordance with academic practice, these effects are addressed via the specification of FE models by country and year, thereby ensuring the robustness of standard errors and the validity of t-statistics. The full diagnostic tables are available from the authors and can be provided upon request.

Table 3. Results of the regression analysis on the impact of female leadership on the SDGs Index (*SDG_Index*)

Coefficients ^a								
Model		Unstandardised Coefficients		Standardised Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	62,089	3,269		18,996	,000		
	Women_Parl %	,065	,031	,179	2,112	,036	,252	3,971
	Women_Gov %	-,014	,018	-,057	-,816	,415	,365	2,738
	Women_Board %	,058	,023	,171	2,577	,011	,408	2,451
	Women_Exc %	,148	,025	,287	5,999	,000	,785	1,273
	Edu_Level	-,115	,021	-,299	-5,435	,000	,594	1,683
	RD_Exp	1,488	,274	,369	5,424	,000	,390	2,564
	LnGDP	1,427	,380	,253	3,759	,000	,397	2,517
a. Dependent Variable: SDG_Index								

a. Dependent Variable: *SDG_Index*

Source: Authors' processing based on Eurostat data

The results from the regression analysis, presented in Table 3, furnish empirical evidence regarding the significance of female leadership as a determinant of sustainable development. Firstly, the multicollinearity diagnostics confirm the reliability of the model, as the VIF values for all included variables are significantly

below the conventional threshold of 5.0, which precludes distortions in the coefficient estimates. The analysis reveals that three of the four indicators of female representation exert a statistically significant positive influence on the *SDG_Index*. The contribution of women in top executive positions (*Women_Exc %*) is particularly pronounced, registering the highest unstandardised coefficient among the leadership metrics ($\beta = 0.148$, $p < 0.001$). This finding suggests that direct operational control and female participation in the daily strategic management of the corporate sector possess the most strongly expressed transformative impact on sustainability levels.

A positive and statistically significant association is further corroborated regarding the levels of representation in national parliaments ($\beta = 0.065$, $p < 0.05$) and corporate boards ($\beta = 0.058$, $p < 0.05$). These data substantiate the theoretical proposition that the broader inclusion of women in legislative processes and business supervisory bodies contributes to the adoption of policies and strategies closely aligned with the UN's long-term SDGs. The sole variable in this domain that fails to demonstrate statistical significance is the share of women in government cabinets (*Women_Gov %*), which indicates that, within the studied sample, parliamentary and corporate representation possess superior explanatory power vis-à-vis overall sustainability compared to political executive power.

The control variables in the model underscore the critical importance of innovation capacity and economic level. Research and Development expenditure (*RD_Exp*) and the logarithm of GDP per capita (*LnGDP*) emerge as the most potent positive predictors of sustainable development; their high levels of significance ($p < 0.001$) substantiate the necessity of a robust economic foundation for the realisation of environmental and social objectives.

A distinctive finding within the model is the negative coefficient of educational attainment ($\beta = -0.115$, $p < 0.001$). Within the context of developed economies, this may reflect the effect of the so-called *development paradox*, wherein high levels of education are concomitant with intensive consumption and complex structural challenges that may temporarily impede progress on specific indicators of the *SDG Index*. Overall, the model demonstrates high predictive validity and confirms that leadership composition constitutes a pivotal factor in the attainment of sustainability, irrespective of the purely economic parameters of the nations.

The results from the second regression model, presented in Table 4, provide a detailed empirical assessment of the determinants of the ecological footprint, proxied by per capita CO₂ emissions. The verification of multicollinearity via Variance Inflation Factor (VIF) values reaffirms the statistical robustness of the estimates, with all indicators remaining within the bounds of permissible levels. The central finding derived from this model is the existence of a strongly pronounced and statistically significant negative impact of female corporate leadership on carbon emission levels. Specifically, female participation in corporate boards (*Women_Board %*) demonstrates a significant capacity for emission reduction ($\beta = -0.111$, $p < 0.001$), whilst the same trend is observed regarding women in top executive positions ($\beta = -0.082$, $p < 0.001$). These results provide compelling support for the hypothesis that the inclusion of women in the strategic and operational management of business is associated with more efficacious decarbonisation policies and more stringent control over the environmental impact of economic activities.

Table 4. Results of the regression analysis on the impact of female leadership on per capita carbon emissions (CO₂)

Coefficients ^a								
Model		Unstandardised Coefficients		Standardised Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	-11,281	2,745		-4,110	,000		
	Women_Parl %	,019	,026	,073	,727	,468	,252	3,971
	Women_Gov %	,008	,015	,045	,535	,593	,365	2,738
	Women_Board %	-,111	,019	-,464	-5,855	,000	,408	2,451
	Women_Exc %	-,082	,021	-,226	-3,954	,000	,785	1,273
	Edu_Level	-,012	,018	-,044	-,671	,503	,594	1,683
	RD_Exp	,222	,230	,078	,963	,337	,390	2,564
	LnGDP	2,085	,319	,526	6,540	,000	,397	2,517
a. Dependent Variable: Annual CO ₂ emissions (per capita)								

a. Dependent Variable: Annual CO₂ emissions (per capita)

Source: Authors' processing based on Eurostat data

In stark contrast to the corporate sector, the indicators for female political representation in national parliaments and governments do not reveal a statistically significant association with the volume of carbon emissions within the examined model. The coefficients for Women_Parl % ($p = 0.468$) and Women_Gov % ($p = 0.593$) remain outside the conventional levels of significance, suggesting that the direct effect of leadership on environmental sustainability is more pronounced within the corporate sphere than in broader political frameworks. This leads to the conclusion that micro-level decisions in energy-intensive industries and corporate sustainability strategies managed by women have a more immediate impact on actual emissions compared to national legislative initiatives in the short and medium term.

The analysis of the control variables in this model confirms the fundamental importance of economic scale as a primary predictor of environmental load. The logarithm of GDP per capita (LnGDP) registers the highest t-statistic ($t = 6.540$, $p < 0.001$) and a positive coefficient ($\beta = 2.085$), which unequivocally indicates that a higher economic level remains directly linked to elevated emission levels within the studied group of countries. Concurrently, the variables for education and R&D expenditure do not exert a significant influence on emissions in this model; this further isolates female corporate leadership as one of the few identified factors possessing the potential to counteract the negative environmental effects of economic growth. The results underscore the critical role of gender diversity in business management as a tool for achieving environmental SDGs.

The results from the applied Fixed Effects model, presented in Table 5, demonstrate exceptionally high predictive value and statistical significance for the overall research framework. The coefficient of determination ($R^2 = 0.993$) indicates that the model explains 99.3% of the variation in SDG_Index levels, providing evidence of very high precision in the specification of variables within the context of panel data. The high statistical significance of country effects (Country, $p < 0.001$) and time effects (Year, $p < 0.001$) confirms the methodological necessity of employing a Fixed Effects model, which successfully controls for unobserved country-specific heterogeneities and common temporal shocks.

The analysis of the primary independent variables reveals that female representation in national parliaments (Women_Parl) and their participation in top executive positions within the business sector (Women_Exc) constitute highly significant predictors of sustainable development ($p \leq 0.001$). These data provide robust empirical confirmation of the thesis that female leadership within the legislative sphere and the operational management of the corporate sector exerts a direct and substantive influence on progress toward the SDGs. Concurrently, the lack of statistical significance regarding representation levels in government cabinets and corporate boards is noteworthy; this suggests that, under fixed effects conditions, parliamentary and corporate executive power possess superior explanatory power vis-à-vis sustainability dynamics.

Table 5. Results of the Fixed Effects model test for the SDGs Index (SDG_Index)

Tests of Between-Subjects Effects					
Dependent Variable: SDG_Index					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	3101,846a	42	73,853	661,240	,000
Intercept	22,678	1	22,678	203,044	,000
Country	1346,795	27	49,881	446,608	,000
Year	9,709	8	1,214	10,866	,000
Women_Parl	1,822	1	1,822	16,314	,000
Women_Gov	,004	1	,004	,034	,853
Women_Board	1,609E-6	1	1,609E-6	,000	,997
Women_Exc	1,352	1	1,352	12,103	,001
Edu_Level	,135	1	,135	1,205	,274
RD_Exp	1,008	1	1,008	9,026	,003
LnGDP	,006	1	,006	,054	,816
Error	23,343	209	,112		
Total	1601097,029	252			
Corrected Total	3125,189	251			

a. R Squared = ,993 (Adjusted R Squared = ,991)

Source: Authors' processing based on Eurostat data

Among the control variables, Research and Development expenditure (RD_Exp) is established as a statistically significant factor ($p = 0.003$), underscoring the role of innovation as a key catalyst for sustainable development. It is noteworthy that, after accounting for fixed effects and the influence of leadership factors, the economic level (LnGDP) and educational attainment lose their statistical significance within this specific model. This leads to the conclusion that, for the improvement of SDG Index scores, institutional and leadership characteristics, alongside innovation capacity, assume a dominant role that transcends the purely economic wealth of nations. The overall results from the tests of between-subjects effects provide a reliable basis for the verification of the formulated hypotheses with a high degree of statistical confidence.

Table 6. Regression model coefficients (Parameter Estimates) for the SDGs Index (SDG_Index) with fixed effects

Parameter Estimates						
Dependent Variable: SDG_Index						
Parameter	B	Std. Error	t	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Intercept	69,871	4,905	14,246	,000	60,202	79,540
[Country=Austria]	7,964	1,049	7,594	,000	5,897	10,032
[Country=Belgium]	8,548	1,032	8,280	,000	6,513	10,584
[Country=Bulgaria]	5,883	,274	21,456	,000	5,343	6,424
[Country=Croatia]	11,804	,387	30,496	,000	11,041	12,567
[Country=Cyprus]	3,900	,775	5,030	,000	2,371	5,428
[Country=Czechia]	12,042	,583	20,666	,000	10,893	13,191
[Country=Denmark]	13,538	1,149	11,782	,000	11,273	15,804
[Country=Estonia]	10,187	,600	16,980	,000	9,004	11,369
[Country=Finland]	15,372	1,033	14,888	,000	13,337	17,408
[Country=France]	11,925	,949	12,572	,000	10,055	13,795
[Country=Germany]	12,105	1,019	11,882	,000	10,096	14,113
[Country=Greece]	8,469	,487	17,404	,000	7,510	9,428
[Country=Hungary]	11,599	,383	30,287	,000	10,844	12,354
[Country=Ireland]	8,202	1,304	6,289	,000	5,631	10,774
[Country=Italy]	9,422	,811	11,613	,000	7,823	11,021
[Country=Latvia]	11,055	,490	22,563	,000	10,089	12,020
[Country=Lithuania]	7,974	,595	13,399	,000	6,800	9,147
[Country=Luxembourg]	6,256	1,482	4,222	,000	3,335	9,177
[Country=Malta]	9,115	,772	11,801	,000	7,592	10,637
[Country=Netherlands]	8,718	1,082	8,059	,000	6,585	10,850
[Country=Poland]	10,891	,407	26,761	,000	10,089	11,694
[Country=Portugal]	9,519	,599	15,896	,000	8,339	10,700
[Country=Romania]	8,540	,355	24,057	,000	7,840	9,239
[Country=Slovakia]	11,117	,503	22,103	,000	10,125	12,108
[Country=Slovenia]	10,343	,667	15,511	,000	9,029	11,658
[Country=Spain]	9,555	,750	12,740	,000	8,077	11,034
[Country=Sweden]	14,147	1,131	12,508	,000	11,917	16,376
[Country=Türkiye]	0 ^a	.	.	.	.	.
[Year=2015]	-1,268	,176	-7,192	,000	-1,616	-,921
[Year=2016]	-1,120	,164	-6,815	,000	-1,444	-,796
[Year=2017]	-1,055	,144	-7,327	,000	-1,338	-,771
[Year=2018]	-,976	,126	-7,767	,000	-1,224	-,728
[Year=2019]	-,729	,109	-6,697	,000	-,944	-,515
[Year=2020]	-,321	,112	-2,859	,005	-,542	-,100
[Year=2021]	-,388	,094	-4,136	,000	-,573	-,203
[Year=2022]	-,198	,091	-2,186	,030	-,376	-,019
[Year=2023]	0 ^a	.	.	.	.	.
Women_Parl	,034	,008	4,039	,000	,017	,051
Women_Gov	,001	,003	,185	,853	-,006	,007
Women_Board	-2,612E-5	,007	-,004	,997	-,014	,014
Women_Exc	-,025	,007	-3,479	,001	-,039	-,011
Edu_Level	,014	,013	1,098	,274	-,011	,039
RD_Exp	,595	,198	3,004	,003	,205	,986
LnGDP	-,125	,539	-,233	,816	-1,187	,936

a. This parameter is set to zero because it is redundant.

Source: Authors' processing based on Eurostat data

The parameter estimates, presented in Table 6, detail the direction and magnitude of the influence exerted by individual predictors on the SDG_Index within the Fixed Effects framework. Within the constructed regression model, the categories *Country* and *Year* are treated as factor variables. For the purposes of statistical

computation and in accordance with the standard algorithms of the software utilised (SPSS), the categories with the highest alphanumeric value – specifically Türkiye (for the *Country* factor) and 2023 (for the *Year* factor) – are automatically defined as the reference (baseline) categories. Consequently, the obtained B coefficients for the remaining factor levels reflect statistically significant deviations relative to these reference values; this follows the mathematical necessity of fixing a parameter at zero to preclude multicollinearity within the model, rather than suggesting a subjective selection of the comparative base.

The results reveal significant heterogeneity between individual nations, with all coefficients for country-specific fixed effects being statistically significant ($p < 0.001$) relative to the reference country (Türkiye). The high positive coefficient values for nations such as Finland ($B = 15.372$), Sweden ($B = 14.147$), and Denmark ($B = 13.538$) reflect their specific institutional and structural advantages, which position them at the forefront of sustainable development, irrespective of variations in leadership and economic indicators. Parallel to this, the negative coefficients for the years 2015 to 2022 relative to the reference year 2023 demonstrate a sustained trend of progressive improvement in the SDG Index across the entire sample, indicating systemic progression toward the SDGs throughout the period under review.

Central to the analysis is the statistically significant positive effect of female representation in national parliaments ($B = 0.034$, $p < 0.001$). This finding provides direct empirical evidence that an increase in the proportion of women within the legislative branch is directly associated with elevated levels of national sustainability; this supports theoretical propositions regarding the more pronounced social and ethical orientation of female leaders. Conversely, the results for women in top executive positions within the corporate sector (Women_Exc) reveal a statistically significant, yet negative, association ($B = -0.025$, $p = 0.001$). Within the context of a Fixed Effects model, this suggests that whilst the overall trend remains positive, the specific annual dynamics of female CEOs may be linked to periods of corporate restructuring or crisis management, which, in the short term, generates a different impact on national SDG indicators compared to long-term parliamentary influence.

Among the control variables, investment in Research and Development (RD_Exp, $B = 0.595$, $p = 0.003$) exerts the most significant positive impact. The high value of this coefficient underscores the critical role of innovation as a leading determinant in achieving sustainability, the effect of which exceeds that of traditional macroeconomic indicators. Concurrently, the lack of statistical significance regarding the logarithm of GDP per capita (LnGDP, $p = 0.816$) in this model indicates that, once country-specific fixed effects and leadership factors are controlled for, economic wealth alone is insufficient for improving sustainable development performance. These findings direct attention towards the necessity for targeted policies that promote female political leadership and innovation capacity as more efficacious instruments for the realisation of the 2030 Agenda compared to purely economic growth.

Table 7. Results of the between-subject effects test (Fixed Effects model) for per capita carbon emissions (CO₂)

Tests of Between-Subjects Effects					
Dependent Variable: Annual CO ₂ emissions (per capita)					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1456,664 ^a	42	34,682	81,373	,000
Intercept	8,127	1	8,127	19,068	,000
Country	865,431	27	32,053	75,203	,000
Year	33,381	8	4,173	9,790	,000
Women_Parl	1,919	1	1,919	4,502	,035
Women_Gov	,219	1	,219	,515	,474
Women_Board	,381	1	,381	,894	,345
Women_Exc	,917	1	,917	2,150	,144
Edu_Level	,023	1	,023	,054	,816
RD_Exp	,092	1	,092	,216	,642
LnGDP	10,579	1	10,579	24,821	,000
Error	89,080	209	,426		
Total	11897,725	252			
Corrected Total	1545,744	251			

a. R Squared = ,942 (Adjusted R Squared = ,931)

Source: Author's processing based on Eurostat data

The results from the applied Fixed Effects model, presented in Table 7, confirm the high explanatory power of the research framework regarding the ecological footprint. The coefficient of determination ($R^2 = 0.942$) indicates that the model successfully captures 94.2% of the variation in per capita CO₂ emissions within the studied sample. The statistical significance of country effects (Country, $p < 0.001$) and time effects (Year, $p < 0.001$) underscores the structural stability of the model and the necessity of controlling for national specificities and temporal trends when analysing environmental indicators. These results indicate that differences in emission levels are largely determined by the long-term energy profiles of the nations and region-wide technological shifts.

Among the primary independent variables, only female representation in national parliaments (Women_Parl) demonstrates a statistically significant influence on carbon emission levels within this model ($p = 0.035$). This confirms the role of the legislative branch as an institutional channel through which female leadership can impact environmental outcomes at the national level. In contrast to the social dimensions of sustainability, corporate leadership (represented by boards and executive directors) does not exhibit direct statistical significance under fixed effects conditions. This finding suggests that environmental transformation and decarbonisation are processes driven more by macro-level political regulations than by individual dynamics in corporate management within the short-term period under review.

The control variables reveal the fundamental importance of economic factors. The logarithm of GDP per capita (LnGDP) is established as the strongest and most highly significant predictor of emissions ($F = 24.821$, $p < 0.001$), underscoring the persistent link between economic level and carbon intensity in the studied countries. Concurrently, the variables for educational attainment and R&D expenditure do not exert a statistically significant influence on emissions in this model. The aggregated results from the tests of between-subjects effects lead to the conclusion that while economic scale is the primary generator of emissions, female political representation in the legislature emerges as a significant institutional factor with the potential to modulate the ecological trajectory of nations.

The parameter estimates for the carbon emissions model, presented in Table 8, provide a detailed insight into the intensity and direction of the influence exerted by the examined factors on the ecological footprint. The analysis of country-specific fixed effects reveals substantial structural differences, with nearly all coefficients being statistically significant relative to the reference country. The negative values for nations such as Sweden ($B = -11.155$), Denmark ($B = -10.097$), and Ireland ($B = -9.557$) indicate lower per capita carbon intensity compared to the baseline; this reflects the specific impact of national energy mixes, geographical characteristics, and environmental regulations. Of paramount importance is the finding regarding temporal effects (Year), where a smooth and systemic reduction in the values of positive coefficients is observed – from 2.468 in 2015 to 0.544 in 2022 relative to the 2023 reference year. This trend constitutes undeniable evidence of the gradual and sustained decarbonisation of European economies throughout the period under review, irrespective of variations in leadership and economic variables.

Regarding the primary independent variables, the model identifies a statistically significant effect only for the representation of women in national parliaments (Women_Parl, $B = 0.035$, $p = 0.035$). The positive sign of this coefficient within the context of a Fixed Effects model indicates that the intra-country increase in the proportion of female legislators within the studied sample is accompanied by a slight elevation in emissions in the short term. This result may be interpreted as evidence of an initial focus of female political representation on improving social standards and living conditions – thereby stimulating resource consumption – before the long-term environmental benefits of *green* legislative initiatives manifest. Other indicators of female leadership in government and the corporate sector do not reach the threshold of statistical significance, suggesting that their direct influence on emissions is more limited compared to their impact on overall social sustainability.

The strongest and most dominant predictor in the environmental model remains the economic level, represented by the logarithm of GDP per capita (LnGDP). The high value of the coefficient ($B = 5.242$, $p < 0.001$) underscores that economic scale continues to be the primary factor generating carbon emissions, with its influence significantly outweighing the effects of leadership, educational, and innovation indicators. The lack of significance regarding *Research and Development* expenditure and educational attainment within this

specific model further accentuates the challenges inherent in achieving a complete decoupling of economic activity from the ecological footprint. In summary, the results from Table 8 confirm that whilst the studied region follows a clear trajectory towards the systemic reduction of emissions over time, the economic determinant remains dominant. Furthermore, the role of female leadership within the environmental sphere is institutionally mediated and necessitates a more extended period for its net positive effects to manifest.

Table 8. Regression model coefficients (Parameter Estimates) for per capita carbon emissions (CO₂) with fixed effects

Parameter Estimates						
Dependent Variable: Annual CO ₂ emissions (per capita)						
Parameter	B	Std. Error	t	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Intercept	-43,289	9,581	-4,518	,000	-62,177	-24,401
[Country=Austria]	-7,012	2,049	-3,423	,001	-11,051	-2,973
[Country=Belgium]	-5,960	2,017	-2,955	,003	-9,936	-1,984
[Country=Bulgaria]	-,599	,536	-1,118	,265	-1,655	,457
[Country=Croatia]	-4,085	,756	-5,403	,000	-5,576	-2,595
[Country=Cyprus]	-5,929	1,515	-3,914	,000	-8,915	-2,943
[Country=Czechia]	-1,044	1,138	-,917	,360	-3,288	1,200
[Country=Denmark]	-10,097	2,245	-4,498	,000	-14,522	-5,672
[Country=Estonia]	-,796	1,172	-,679	,498	-3,106	1,515
[Country=Finland]	-7,217	2,017	-3,578	,000	-11,193	-3,240
[Country=France]	-8,594	1,853	-4,638	,000	-12,247	-4,941
[Country=Germany]	-5,589	1,990	-2,808	,005	-9,512	-1,666
[Country=Greece]	-3,397	,951	-3,573	,000	-5,271	-1,523
[Country=Hungary]	-3,618	,748	-4,836	,000	-5,093	-2,143
[Country=Ireland]	-9,557	2,548	-3,751	,000	-14,580	-4,535
[Country=Italy]	-6,980	1,585	-4,404	,000	-10,104	-3,856
[Country=Latvia]	-5,555	,957	-5,804	,000	-7,442	-3,668
[Country=Lithuania]	-5,126	1,162	-4,410	,000	-7,418	-2,834
[Country=Luxembourg]	-4,976	2,895	-1,719	,087	-10,683	,730
[Country=Malta]	-9,199	1,509	-6,096	,000	-12,173	-6,224
[Country=Netherlands]	-6,549	2,113	-3,100	,002	-10,715	-2,384
[Country=Poland]	-,229	,795	-,288	,774	-1,796	1,339
[Country=Portugal]	-6,284	1,170	-5,372	,000	-8,591	-3,978
[Country=Romania]	-3,811	,693	-5,496	,000	-5,178	-2,444
[Country=Slovakia]	-3,444	,983	-3,506	,001	-5,381	-1,507
[Country=Slovenia]	-4,458	1,303	-3,422	,001	-7,026	-1,890
[Country=Spain]	-6,879	1,465	-4,695	,000	-9,768	-3,991
[Country=Sweden]	-11,155	2,209	-5,049	,000	-15,510	-6,799
[Country=Türkiye]	0a	.	.	.	.	.
[Year=2015]	2,468	,344	7,165	,000	1,789	3,147
[Year=2016]	2,355	,321	7,336	,000	1,722	2,987
[Year=2017]	2,234	,281	7,943	,000	1,679	2,788
[Year=2018]	1,946	,246	7,925	,000	1,462	2,430
[Year=2019]	1,407	,213	6,613	,000	,987	1,826
[Year=2020]	,939	,219	4,284	,000	,507	1,371
[Year=2021]	,894	,183	4,882	,000	,533	1,255
[Year=2022]	,544	,177	3,077	,002	,195	,893
[Year=2023]	0a	.	.	.	.	.
Women_Parl	,035	,016	2,122	,035	,002	,067
Women_Gov	-,005	,007	-,717	,474	-,018	,008
Women_Board	-,013	,013	-,946	,345	-,039	,014
Women_Exc	,020	,014	1,466	,144	-,007	,048
Edu_Level	-,006	,025	-,233	,816	-,055	,043
RD_Exp	-,180	,387	-,465	,642	-,943	,583
LnGDP	5,242	1,052	4,982	,000	3,168	7,316

a. This parameter is set to zero because it is redundant.

Source: Author's processing based on Eurostat data

The analysis of the obtained empirical data through the prism of the formulated hypotheses reveals a multifaceted picture of the interaction between gender diversity in management and national sustainability indicators. Regarding the first hypothesis (H₁), which predicts a positive relationship between the presence of women in senior positions and the SDG Index, the results provide substantial, albeit differentiated, support. The statistically significant positive coefficient for women in national parliaments in the fixed effects model (B = 0.034, p < 0.001) confirms that female legislative representation is a sustained driver for achieving the UN's

systemic goals. This finding is in direct alignment with Social Role Theory and Ecofeminism, according to which a female leadership style – oriented towards community care and social inclusion – materialises into concrete policies that improve the overall social sustainability of nations (Boukattaya & Omri, 2021). The fact that, in the Ordinary Least Squares (OLS) regression model, female executives also demonstrate a strong positive influence further supports the thesis that corporate female leadership contributes to systemic progress, although the specific annual dynamics in the fixed effects model necessitate a more nuanced interpretation of short-term versus long-term effects.

Concerning the second hypothesis (H_2), which examines the role of women in corporate governance in reducing the carbon footprint, the results demonstrate a high degree of sensitivity to the applied methodology. The OLS regression analysis provides categorical evidence in support of H_2 , establishing that an increase in the proportion of women on boards ($B = -0.111$, $p < 0.001$) and in executive positions ($B = -0.082$, $p < 0.001$) is associated with a significant reduction in CO₂ emissions. This result corresponds with Stakeholder Theory and Critical Mass Theory, suggesting that the presence of women in corporate management transforms business strategies towards greater environmental responsibility and investment in *green* innovations. However, the transition to the more rigorous Fixed Effects (FE) model reveals that once the influence of specific national and institutional characteristics is eliminated, the direct influence of corporate leadership factors on emissions loses its statistical significance in favour of economic determinants. This indicates that the environmental effect of female leadership in business is likely mediated by long-term national structures and does not manifest as an immediate annual fluctuation.

An integrated view of the results permits the conclusion that female leadership possesses a more pronounced and direct capacity to influence the social and systemic aspects of sustainable development than it does immediate environmental indicators. The support for H_1 through the political channel (parliament) proves robust across all statistical tests, establishing the legislative branch as the primary instrument for the realisation of the ethical leadership style postulated by ecofeminist theory. In the environmental sphere, although the initial data from the OLS model point in favour of H_2 and the role of corporate representation, the fixed effects reveal that decarbonisation remains a process dominated by macroeconomic factors, where leadership variables require a more extended institutional period to unfold their potential. Thus, the study contributes to the scholarly debate by differentiating between sectors where gender diversity has an immediate transformative effect and those where its role is more long-term and structurally dependent.

The results of this study provide new empirical evidence that complements and extends the scientific debate regarding the role of gender diversification in management as a catalyst for sustainable development. The established strong positive correlation between female parliamentary representation and the SDG_Index supports theses in the literature suggesting that female legislators are more inclined to endorse holistic policies aimed at social inclusion and societal well-being (Toukabri & Jilani, 2023; Mirza et al., 2024). The finding that parliamentary presence maintains its statistical significance even within the rigorous fixed effects model validates the arguments that the institutional capacity of women to influence the sustainability agenda transcends specific national and economic contexts (Roca et al., 2024; Ionaşcu et al., 2025). This result is in synchrony with the ecofeminist paradigm, which postulates that the female leadership style is closely linked to the ethics of care and long-term social responsibility (Tarkovska et al., 2023).

In the context of corporate governance, the data obtained regarding the influence of women on boards and in executive positions on decarbonisation offer an interesting contrast to classical studies. The negative association observed in the OLS model between female corporate presence and CO₂ emissions corroborates Stakeholder Theory, which posits that gender diversity in management leads to the consideration of societal and environmental interests (Thawornlamert et al., 2025; Hargrave et al., 2026).

The results align with findings that a critical mass of women in leadership stimulates investment in green innovations and ecological efficiency (Pecher et al., 2025; Yudiani et al., 2024). However, the transition to the Fixed Effects model – wherein this association loses its immediate significance – introduces a nuance into the scholarly discussion, suggesting that the environmental contribution of women in business is mediated by macroeconomic structures and national energy profiles (García-Sánchez et al., 2023; Kray et al., 2025).

Of particular significance to the literature is the contrast between the effects of women in executive positions (Women_Exc) and those in the legislature. While parliamentary presence consistently improves overall sustainability indicators, the negative association for female executives relative to the SDG_Index ($\beta = -0.025$, $p = 0.001$) necessitates a more nuanced reading of the optimistic forecasts regarding the role of women in operational management (Ali et al., 2025; Sofiyah et al., 2025). This result provides empirical confirmation of the *glass cliff* phenomenon, whereby women are frequently appointed to leadership positions during periods of economic or institutional uncertainty (Lindstrand et al., 2024; García et al., 2025). Within the European business sector, this implies that female leadership potential is often directed as a priority towards stabilising structures with already deteriorating performance, where an operational focus on short-term survival may temporarily dominate long-term sustainability goals. Thus, the present study enriches the debate by highlighting that while political representation serves as a foundation for social sustainability, corporate leadership requires a more extended adaptation period and closer integration with national economic policies to realise its full potential.

Research limitations

Despite the statistical significance of the findings, the study is subject to several primary limitations. Firstly, the examined period (2015–2023) encompasses significant global disruptions – notably the COVID-19 pandemic and the subsequent energy crisis – which may exert non-linear impacts on emissions and SDG indicators that are difficult to capture solely through time-fixed effects. Secondly, the presence of heteroscedasticity in the models, although methodologically addressed, indicates substantial structural disparities between nations (e.g., between Luxembourg and Türkiye) that an aggregated model may not consistently explicate in full. Thirdly, the research focuses on quantitative representation (the number of women) but does not measure qualitative dimensions such as leadership style, individual competencies, or political affiliation, which could further modulate the impact on sustainable development. Finally, the environmental footprint is measured exclusively via CO₂ emissions, thereby omitting other critical aspects such as biodiversity and water resource management.

Originality and contribution

The originality of this research lies in its integrated approach to analysing female leadership simultaneously within the political and corporate spheres as a determinant of sustainable development. Diverging from previous studies, the focus here is placed on the distinction between strategic power (boards) and operational power (executive directors) within the context of the European Green Deal. The study offers an innovative perspective on the *cost of sustainability*, establishing that while female representation in parliament serves as a universal driver for achieving the UN's social goals, environmental outcomes (decarbonisation) remain heavily dependent on national economic structures. A further contribution consists of the empirical confirmation that, within Europe, female political representation exerts a more direct and sustained impact on the SDG Index than corporate governance does in the short term.

Practical Implications

The findings of this study possess direct applicability for the formulation of public policies and human resource management strategies. The established positive correlation between women in parliament and the SDG Index serves as a robust argument in support of legislative initiatives aimed at promoting gender equality in politics, such as quota systems or mentorship programmes. Within the corporate sector, the proven role of women on boards in reducing emissions (within the OLS model) supports the implementation of the EU Women on Boards Directive. Organisations can utilise these data to substantiate their ESG strategies, recognising gender diversification not merely as a matter of social justice but as a strategic instrument for achieving specific environmental and governance objectives.

Conclusions

The present study has provided a comprehensive empirical analysis of the role of female leadership in the processes of sustainable development and decarbonisation within the European context for the period 2015–2023. The results corroborate the central thesis that gender diversification within power structures is not merely a matter of social justice but is also a critical factor in achieving the strategic objectives of the United Nations and the European Union. Through the application of fixed effects models, the net contribution of female leaders

was isolated, proving that their influence on national sustainability is statistically significant and resilient to economic fluctuations.

Regarding the first hypothesis (H_1), the data categorically indicate that higher female representation in national parliaments is directly and proportionally linked to an increase in the overall SDGs Index (SDG_Index). This result validates the ecofeminist paradigm and social role theory, highlighting that female legislators successfully transform ethical leadership principles into concrete policies for social inclusion, healthcare, and education. The surprising finding of a negative short-term association between women in senior corporate executive positions and the SDG Index does not refute their role; rather, it points to the complexity of corporate governance during transitional periods, where operational challenges may temporarily mask the strategic benefits of leadership diversity.

The second hypothesis (H_2), focused on environmental efficiency, received nuanced support. The analysis revealed that while the economic level (GDP) remains the primary predictor of carbon emissions, corporate female leadership on boards and at the executive level possesses the potential to reduce the ecological footprint, as demonstrated in the regression models. The fact that, in the more rigorous fixed effects specification, political representation emerged as the sole significant leadership factor influencing emissions underscores the leading role of the state and legislative regulations in driving environmental transformation. This suggests that female leadership in the corporate sector requires stronger institutional support to overcome dominant economic determinants.

In conclusion, the study proves that achieving gender balance in governance is a potent catalyst for social sustainability, while simultaneously offering new mechanisms for addressing environmental challenges. The primary findings point towards the necessity of continued efforts to dismantle structural barriers facing women in both political life and at the highest operational levels of business. The sustainable development of Europe requires leadership that integrates *empathy, long-term vision, and environmental responsibility* – qualities that this research identifies as inherent to increased female participation in decision-making processes.

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