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ASSESSING ENERGY CONSUMPTION AND GREENHOUSE GAS EMISSIONS IN EU MEMBER STATES – DECOMPOSITION ANALYSIS*

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Abstract. This paper addresses the growing global concern regarding energy consumption and its adverse environmental impacts, particularly the increase of greenhouse gas emissions linked to economic development and population growth. To comprehensively assess the environmental implications of energy consumption, a decomposition analysis employing the Index decomposition analysis (IDA) method with the logarithmic mean Divisia index (LMDI) approach was conducted, focusing on the drivers behind energy consumption and greenhouse gas emissions in the EU 27 from 1998 to 2018. This analysis discerns disparities between wealthier and less affluent countries. The findings highlight substantial reductions in greenhouse gas emissions and energy consumption within the EU, primarily attributed to the growing emphasis on reducing the emission intensity targeted by EU policies. Nonetheless, disparities persist among member states, primarily driven by economic activity levels. In relation to the unique economic structures of EU countries results however advocate for diversified approaches tailored to the unique conditions of each Member State to meet the set targets, with an emphasis on fostering collaboration, technology transfer, innovation, and renewable energy adoption to advance sustainability of the region.

Keywords: economic growth; energy consumption; CO_2 emissions; EU 27; decomposition analysis

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1. Introduction

Since the dawn of civilisation, energy has been a driving force behind human progress and development, powering economic growth, transport and industry. However, the production and consumption of energy have also caused significant damage to the environment and human health in the form of climate change, air pollution and natural disasters (Chen et al., 2022; Skare et al., 2023; Androniceanu & Georgescu, 2023).

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Findings from the Intergovernmental Panel on Climate Change (IPCC) report show that human-induced global warming has already exceeded 1°C above pre-industrial levels and is projected to exceed 1.5°C between 2030 and 2045 unless strong mitigation action is taken (IPCC, 2021). The consequences of such changes pose a profound threat to both humanity and ecosystems, leading to extreme weather events, health problems, loss of biodiversity and other negative impacts.

As the issue of the negative impact of energy consumption gains widespread attention, the European Union (EU) is emerging as a proactive actor, setting ambitious targets to achieve climate neutrality within the next three decades. This commitment has increased the urgency of analysing and evaluating the driving forces behind the increase in energy consumption and greenhouse gas emissions in the EU-27.

The main objective of this paper is to conduct a comprehensive decomposition analysis to examine the factors contributing to the growth of energy consumption and greenhouse gas emissions in the European Union. A distinctive feature of this study is that it focuses on the two groups of EU countries based on their Gross Domestic Product (GDP): (1) richer countries with a GDP above the EU-27 average and (2) poorer countries with a GDP below the EU-27 average.

By disaggregating the energy consumption and greenhouse gas emissions data for each group, this study aims to reveal the differences between these so-called rich and poor countries. Such insights gained from the decomposition analysis will facilitate a deeper understanding of the underlying factors driving energy consumption and greenhouse gas emissions in each group, ultimately leading to the identification of effective mitigation strategies and policies to achieve climate neutrality within the EU.

The structure of this paper is as follows: First, we review the theoretical background and evidence from previous empirical studies. Our research methodology, decomposition analysis, and the data sources used are outlined in Section 2. Section 3 is devoted to presenting the results and an in-depth discussion. The final section summarises our findings, policy implications, and research limitations.

2. Literature review

Understanding sustainable development and its interconnectedness with the economic, social, and environmental spheres aims to maintain and stimulate financial growth while considering societal well-being alongside environmental quality (Reyers et al., 2017). Rapid economic development and population growth are closely linked to increased energy demand, which leads to increased greenhouse gas emissions (GHG). In recent decades, there has been a significant global increase in GHG emissions from anthropogenic activities such as transport, electricity generation, heating and cooling of buildings, operation of fuel-burning appliances and equipment, and industrial and manufacturing activities (Kijewska & Bluszcz, 2016; Tyagi et al., 2016; Wang & Feng, 2018).

The largest global energy consumers and GHG emitters are China, the US, India, Russia, Japan, Germany, South Korea, and Canada. The largest share of global GHG emissions is CO2, which is the main driver of climate change and a major contributor to global warming worldwide. For this reason, reducing CO2 emissions has been identified as a new global goal in research and economic development (Nejat et al., 2015; Nordhaus, 2013; Kijewska & Bluszcz, 2016; Xu et al., 2018; Istudor et al., 2021).

Developed countries in Europe and North America, which emitted large amounts of CO2 in the wake of the industrial revolution, have found several ways to reduce CO2 emissions per unit of output in recent decades, such as reducing energy consumption, using less carbon-intensive fuels, or structurally shifting production to less energy-intensive industries (Nordhaus, 2013; Skare et al. 2024).

Decomposition analysis began to be used to study energy consumption and other environmental issues during the energy crisis of the 1970s. Energy prices were skyrocketing, and the intention of many researchers was to use this analysis to find effective channels to reduce energy consumption by decoupling changes in energy consumption and energy intensity (Chontanawat et al., 2020; Ahmad et al. 2022). Decomposition analysis is also used nowadays to investigate the source of emissions growth and intensity change in different economic sectors of developed and developing countries, as climate change and GHG emissions growth are currently a major global concern (Xu & Ang, 2013; Ang, 2015; Simionescu et al. 2021). The results of previous studies using decomposition analysis have shown that CO2 changes in the industrial sector are generally driven by the expansion of manufacturing and a country's industrial development policies. Reducing energy intensity is an important factor in reducing industrial emissions (Chontanawat et al., 2020; Simionescu et al. 2022). (Jeong & Kim, 2013) decomposed greenhouse gas emissions into five different effects, namely activity effect, structural change effect, intensity change effect, fuel mix effect and emission factor effect. Their main finding was that both structural change and intensity change were critical to reducing GHG emissions, but structural change played a larger role than intensity change.

Researching and understanding the relationship between emissions, energy consumption, and economic growth is essential for effectively controlling and reducing emissions to ensure the sustainability of economic development. These key indicators indicate whether policies can be designed and implemented to improve energy efficiency. In designing and implementing these policies, it is also useful to have reliable information on the main drivers of emissions change. This clearly includes indicators such as population growth and gross domestic product (Román et al., 2018; Wang et al., 2014; Mohmmed et al., 2019). Most research has been conducted in developed countries, and previous studies have shown that economic activity and population growth are the main drivers of emissions change (Bhattacharyya & Matsumura, 2010; Cansino et al., 2016; Drastichová, 2017; Kisielewicz et al., 2019). Within developing countries, studies have shown that economic activity and structural change are the main drivers of economy-wide emissions changes (Xu et al., 2014; Qi et al., 2016; Chong et al., 2019). An overview of the studies conducted in the study area, primarily using the IDA with the LMDI methodology, along with their objectives and main findings, is provided in Table 1.

Table 1. Overview of previous research

Authors	**Aims of the study**	**Methods**	**Findings**
(Löschel et al., 2015)	- to investigate the forces driving improvements in energy intensity in the European Union between 1995 and 2009	- The Logarithmic Mean Divisia Index (LMDI) decomposition (factors: energy use, GDP, energy intensity, trade openness, capital intensity, productivity, energy prices)	- The factors such as economic growth, capital intensity, and energy prices affect energy intensity.
(Achour & Belloumi, 2016)	- to analyze the Tunisian transportation sector over the period 1985–2014; - to identify the driving factors and measure their corresponding contributions in transport related energy consumption	- The Logarithmic Mean Divisia Index (LMDI) decomposition using Tunisian statistical data from an extensive time series of 30 years covering the period of 1985–2014 (factors: population, road-related energy consumption, gross domestic product, civil aviation, rail, water transport-related energy consumption)	- The overall effect of economic output, transportation intensity, population scale, transportation structure on energy consumption is positive, and the overall effect of energy intensity is negative. - Energy intensity played the dominant role in decreasing energy consumption.
(Karmellos et al., 2016)	- to investigate the driving factors of CO_2 emissions from electricity generation in the European Union countries (EU-28) during the period 2000–2012	- The Logarithmic Mean Divisia Index (LMDI) decomposition (factors: level of activity, electricity intensity, electricity trade, efficiency of electricity generation and fuel mix)	- In times of economic growth, the main factor counterbalancing the activity effect was, in most countries, the decreasing electricity intensity, while the contribution of all other factors became apparent later, despite the economic crisis and in view of the Kyoto targets.
(Mousavi et al., 2017)	- to quantify driving forces of CO_2 emissions in Iran as the one of the top ten CO_2 emitting countries	- The Logarithmic Mean Divisia Index (LMDI) decomposition (factors: population, affluence, energy intensity of economy, carbon intensity of energy use, fuel consumption)	- The main driver of Iran's CO_2 emissions is increased consumption. - Natural gas capacity, especially in the transport sector, helps improve the energy mix but would require more.
(Boqiang & Liu, 2017)	- to explore the influencing factors of CO2 emissions from China's heavy industry during 1996-2015	- The Logarithmic Mean Divisia Index (LMDI) decomposition (factors: carbon intensity, energy efficiency, income, population,	- The labour productivity, energy intensity, and industry scale are the

		energy structure, industry scale, energy intensity, labour productivity)	main factors affecting CO_2 emissions in heavy industry. - The improvement of labour productivity is the main cause of the increase in CO_2 emissions; a decline in energy intensity leads to CO_2 emissions reduction, and the industry scale has different effects.
(Chen et al., 2018)	- to explore the impacts of selected factors on CO_2 emissions in the OECD from 2001 to 2015; - to explore the decoupling relationships between the selected factors and CO_2 emissions	- The Logarithmic Mean Divisia Index (LMDI) decomposition (factors: CO_2 emission intensity of fossil energy, energy consumption structure, energy intensity, GDP, population distribution, population size); - Tapia decoupling analysis	- Energy intensity and GDP are the main factors affecting CO_2 emissions. - The impact of population distribution on CO_2 emissions is negligible. - The influence of technical factors is greater than that of non-technical factors, and their influence directions are always opposite.
(Chen et al., 2018)	- to unveil the driving factors behind the changes in greenhouse gases emissions related to internal energy consumption and imbalance of emissions in external trade in Macao during 2000-2011	- The Logarithmic Mean Divisia Index (LMDI) decomposition (factors: economic scale, industry structure, energy intensity, energy structure)	- The economic scale effect and energy structure change were identified as the main driving factors of increasing energy-related emissions, while trade structure and embodied emission intensity contributed to making Macao a net importer of embodied emissions.
(Du et al., 2018)	- to identify the drivers of energy-related CO_2 emissions change of high-energy intensive industries in China during 1986-2013	- The Logarithmic Mean Divisia Index (LMDI) decomposition (factors: industrial scale, industrial structure, energy intensity, energy structure).	- The expansion of industrial scale was the leading force explaining CO_2 emissions change. - Energy intensity was the major contributor to promoting the decline in CO_2 emissions. - The effects of energy structure and industrial structure have relatively small impacts on CO_2 emissions change due to the relatively stable energy structure and industrial structure over the years.
(Mohmmed et al., 2019)	- to identify the drivers and variation of CO_2 emission in the top 10 emitting countries (China, USA, India, Russian Federation, Japan, Germany, South Korea, Iran, Canada and Saudi Arabia) from 1991-2014; - to find the causal relationship between CO_2 emissions and human development, and the impact of CO_2 emission on health life expectancy; - to forecast sector CO_2 emissions over the next 16 years	- The Logarithmic Mean Divisia Index (LMDI) decomposition (factors: population, income, energy intensity, carbon intensity); - Panel Regression Model; - Autoregressive Integrated Moving Average models to forecast of the sectors´ CO_2 emissions	- The population displayed positive effects on CO_2 change in China, US, India, Korea, Canada, Iran, and Saudi Arabia. - The energy intensity had negative effects on the carbon emissions change in China. - CO_2 emissions from most sectors had a significant relationship with human development and healthy life expectancy and a highly significant relationship with economic growth. - The forecast showed that CO_2 emission would increase significantly by 2030.
(Chontanawat et al., 2020)	- to analyze the sources of changes in CO_2 emissions as well as the CO_2 emission intensity of the manufacturing sector in Thailand in 2000–2018	- The Logarithmic Mean Divisia Index (LMDI) decomposition (factors: emission intensity, energy consumption, total industrial production, structural change)	- The amount of CO_2 emissions and the CO_2 emission intensity increased each year relative to the baseline. - The structural change effect reduced, but the intensity effect increased the amount of CO_2 emissions and the CO_2 emission intensity.

			- The unfavourable CO_2 emission intensity change came from the increased energy intensity of individual industries. The increased use of coal and electricity raised the CO_2 emissions.
(Ortega-Ruiz et al., 2020)	- to analyze the evolution of the main driving forces of CO_2 emissions in India during the period 1990–2016	- The Logarithmic Mean Divisia Index (LMDI) decomposition (factors: population, economic activity, economic structure, energy intensity and energy mix)	- The per capita income is the main contributor to the CO_2 emissions increase. - Energy intensity is the main contributor to the decrease in CO_2 emissions.
(Luo et al., 2021)	- to investigate the potential indicators influencing CO_2 emission in Shanghai during 1995–2017	- The Logarithmic Mean Divisia Index (LMDI) decomposition (factors: motor vehicle amount, disposable personal income, urbanization rate, per motor vehicle secondary industry, per secondary industry population, per residents' income GDP support coefficient, carbon intensity)	- The motor vehicle amount, the disposable personal income, the carbon intensity, and the urbanization rate are the top four driving forces of CO_2 emission.
(Habimana Simbi et al., 2021)	- to analyze the driving forces of CO_2 emissions from economic development in selected African countries during 1984–2014	- The Logarithmic Mean Divisia Index (LMDI) decomposition (factors: emission efficiency, industrial structure, economic growth, population)	- Population and economic growth were the primary driving forces of CO_2 emissions. - Industrial structure and emission efficiency effects partially offset the growth of CO_2 emissions. - The economic growth effect was an offset factor in Central African countries and Zimbabwe due to political instability and economic mismanagement.
(Dai et al., 2021)	- to decompose the national annual greenhouse gases emissions from enteric fermentation and manure management in pig farming in China from 1976 to 2016	- The Logarithmic Mean Divisia Index (LMDI) decomposition (factors: technological progress, structural adjustment in the livestock sector, structural adjustment in agriculture, affluence, population growth)	- The net greenhouse gases emissions from increased carbon dioxide equivalents. - The structural adjustment in agriculture, affluence, and population growth contributed to an increase of the greenhouse gases emissions.
(Wang et al., 2022)	- to explore the changes in carbon emissions and their underlying factors in the post-COVID-19 era from a national and sectoral perspective by drawing on the experience of carbon emissions before and after the 2008 global crisis in major developing and developed countries	- The Logarithmic Mean Divisia Index (LMDI) decomposition (factors: carbon intensity, energy intensity, economic structure, economic level, population scale, carbon emission, energy consumption, gross output of industry)	- The energy intensity and economic level are major contributor and inhibitor to emission reduction. - In developed countries, energy intensity has a stronger impact on carbon emissions than economic level. - Carbon intensity had both positive and negative impact on carbon emission, and population scale drove carbon emission increase, mainly in developing countries. - Industrial carbon emissions continue to decrease in developed countries and increase in developing countries.

Source: own elaboration

Despite the increasing recognition of the European Union (EU) commitment to carbon neutrality and the implementation of various policies and measures to mitigate GHG emissions, there remains a significant research gap on the specific factors driving energy consumption and emissions differences between EU countries at different economic levels. Existing studies have often focused on overall EU trends or on analysing individual countries, but limited attention has been paid to a comprehensive comparison of energy consumed and emitted patterns between richer and poorer countries within the EU-27 (Soltes and Gavurova, 2015; Gavurova et al. 2021; Tkacova and Gavurova, 2023).

This research gap raises important questions about the underlying causes of the disparities in energy consumption between these two groups of countries, and whether the economic development of these countries plays a significant role in shaping their energy demand and emissions profiles. Moreover, a deeper understanding of the key drivers specific to each group could unlock untapped potential for targeted policies and mitigation strategies that better address the unique challenges and opportunities faced by richer and poorer EU Member States.

We can gain valuable insights into the complex dynamics behind energy consumption and emissions in the EU by filling this research gap and conducting a detailed decomposition analysis.

3. Research methods

Decomposition analysis allows us to monitor the driving forces that affect a particular variable. In our case, we will deal with two variables: (1) energy consumption and (2) greenhouse gas emissions. As mentioned in the previous section, the simplicity and flexibility of the IDA method allow its wider use than in the case of SDA, for the implementation of which input-output (I-O) tables are necessary. For this reason, we will use the IDA method for the purposes of our analysis.

Each decomposition analysis begins with the creation of an equation, which is used to define the relationships between the dependent variable and several factors, the so-called driving forces. In this equation, the product of all factors must be equal to the variable whose change is the subject of the analysis.

In this analysis, we observe the influence of three factors:
1) Activity effect: Depending on the industry, this component is measured in different ways. In the case of industry, this is measured as the added value or physical output of the industry.
2) Structure effect: This component represents a combination of activities within the sector and further divides the activity into subsectors.
3) Intensity effect: This component refers to the energy consumption/emission production per unit of activity.
Various decomposition methods can be used within the IDA to quantify the effects of factor changes on the aggregate. The two most used approaches include methods based on the Divisia index, including LMDI, and methods using the Laspeyres index. For both categories, decomposition analysis can be performed additively or multiplicatively. In the case of a multiplicative decomposition, the ratio change of the aggregate is decomposed, and in the case of an additive approach, the total change, or its increment (indicated by the symbol Δ in our analysis) is decomposed.

The differences lie in the ease of presentation and interpretation of the results (Ang & Zhang, 2000). LMDI I is recommended for general use and is also applied in this analysis. The advantage of this approach is, among other things, that it does not leave residues, which is a property of perfect decomposition and can work with zero values in the dataset (Ang, 2004). The logarithmic mean (L) of two positive numbers x and y is defined as:

$$L(x,y) = \frac{y-x}{\ln\frac{y}{x}}; if\ x \neq y; then\ L(x,y) = x \tag{1}$$

According to (Ang & Zhang, 2000), we can express the quantitative basis of IDA using LMDI by equations (4) - (11). The formulas for the multiplicative and additive decomposition of LMDI are expressed using equations (2) and (3):

$$E_{tot} = \frac{E_T}{E_0} = E_{x1} \times E_{x2} \times E_{x3} \ldots \times E_{xn} \tag{2}$$

$$\Delta E_{tot} = E_T - E_0 = \Delta E_{x1} + \Delta E_{x2} + \Delta E_{x3} + \cdots + \Delta E_{xn} \tag{3}$$

Equations (2) and (3) denote that the total environmental impact (Etot) for the period 0 - T is generally decomposed into n factors, where Exn denotes the contribution of the n-th factor to the change in the total environmental effect in the period 0 - T. Etot indicates a change in a variable whose change factors are analyzed. ET is the value of the variable at time T and E0 is the value at time 0.
In a three-factor additive decomposition analysis, ΔEtot is decomposed into an activity effect (ΔEact), a structure effect (ΔEstr) and an intensity effect (ΔEint), and we express it using equation (4):

$$\Delta E_{tot} = E_T - E_0 = \Delta E_{act} + \Delta E_{str} + \Delta E_{int} \tag{4}$$

Using three-factor decomposition analysis, the above three factors are calculated as follows:

$$\Delta E_{act} = \left(\sum_{i=1}^{n} L(E_i^0\ ;\ E_i^T) \times \ln\left(\frac{Y^T}{Y^0}\right)\right) \tag{5}$$

$$\Delta E_{str} = \left(\sum_{i=1}^{n} L(E_i^0\ ;\ E_i^T) \times \ln\left(\frac{S_i^T}{S_i^0}\right)\right) \tag{6}$$

$$\Delta E_{int} = \left(\sum_{i=1}^{n} L(E_i^0\ ;\ E_i^T) \times \ln\left(\frac{I_i^T}{I_i^0}\right)\right) \tag{7}$$

where the symbols Y, S, I denote activity (rate), structure (composition) and intensity effect.

In the case of multiplicative decomposition, we will proceed according to equation (8):

$$E_{tot} = \frac{E_T}{E_0} = E_{act} \times E_{str} \times E_{int} \tag{8}$$

In the case of multiplicative decomposition, the individual factors will be calculated using equations (9) – (11).

$$E_{act} = exp\left(\sum_{i=1}^{n} \frac{L(E_i^T, E_i^0)}{L(E^T, E^0)} \times ln\left(\frac{Y^T}{Y^0}\right)\right) \tag{9}$$

$$E_{str} = exp\left(\sum_{i=1}^{n} \frac{L(E_i^T, E_i^0)}{L(E^T, E^0)} \times ln\left(\frac{S_i^T}{S_i^0}\right)\right) \tag{10}$$

$$E_{int} = exp\left(\sum_{i=1}^{n} \frac{L(E_i^T, E_i^0)}{L(E^T, E^0)} \times ln\left(\frac{I_i^T}{I_i^0}\right)\right) \tag{11}$$

The subject of the research is the EU countries (current composition of 27 countries, without the United Kingdom) in the period 1998 - 2018. We performed the decomposition in both ways: additive and multiplicative.

Moreover, based on average GDP, we have divided EU countries into countries above GDP average (referred to as higher-income countries) and below GDP average (referred to as lower-income countries) and repeated the analysis for both groups of countries. The sources of data are the database of World Bank for GDP (in purchasing power parity in current international dollars) and Eurostat - the European Union's statistical office for greenhouse gas emissions (in thousands of tonnes) and primary energy consumption (in millions of tonnes of oil equivalent).

4. Results of decomposition analysis

Decomposition analysis of energy use

The results of the additive decomposition analysis of energy consumption in relation to GDP show that the most significant impact on energy consumption over the whole period considered, from 1998 to 2018, was due to aggregate activity. However, it is important to note that energy intensity played a crucial role in reducing energy consumption, leading to a notable reduction of 23.43 million tonnes of oil equivalent over the whole period.

For a more comprehensive examination of trends over time, we have divided the observed period into five-year intervals. A closer look at the individual time series reveals an energy-intensive start, with energy consumption showing a notable increase of 76.19 million tonnes of oil equivalent between 1998 and 2003. During this period, the effect of aggregate activity was the main driver of the increase in energy consumption. This was followed by an improvement in the period from 2003 to 2008, when energy consumption continued to increase, but at a more modest rate of 13.53 million tonnes of oil equivalent. This progress can be attributed to the mitigating effect of energy intensity.

A notable breakthrough occurred in the years 2008 to 2013, when there was a remarkable decrease in energy consumption of 103.68 million tonnes of oil equivalent. During this period, the impact of total activity decreased compared to the previous interval, while the mitigating effect of energy intensity increased significantly. This positive trend continued in the period from 2013 to 2018, albeit in a milder form, resulting in a decrease of 9.47 million tonnes of oil equivalent.

The detailed results of the additive decomposition analysis are presented in Table 2.

Table 2. Additive decomposition - breakdown of energy consumption depending on GDP

	1998-2018	1998-2003	2003-2008	2008-2013	2013-2018
Δ Eact=	1217.2590	318.6638	432.5996	159.2453	349.7706
Δ Estr=	32.9709	6.7183	13.7678	10.0539	-2.6590
Δ Eint=	-1273.6600	-249.1920	-432.8370	-272.9790	-356.5820
Δ Etot=	-23.4300	76.1900	13.5300	-103.6800	-9.4700

Source: own calculations

Table 3 presents the results of the multiplicative decomposition of energy consumption in the EU countries, which are consistent with the results of the additive decomposition. The analysis shows an overall decrease in energy consumption of 1.7% over the whole observation period. At the beginning of the study period (1998-2003), energy consumption increased by 5.4%, which continued in the subsequent period from 2003 to 2008, but at a slower rate of 0.9%. In particular, EU countries achieved a significant reduction in energy consumption of 7% between 2008 and 2013, and this downward trend continued between 2013 and 2018, albeit at a lower rate of 0.7%.

Table 3. Multiplicative decomposition - breakdown of energy consumption by GDP

	1998-2018	1998-2003	2003-2008	2008-2013	2013-2018
Eact=	2.4048	2.4058	2.4064	2.4058	2.4061
Estr=	1.0241	0.5213	0.5616	0.4677	0.5345
Eint=	0.3993	0.8408	0.7467	0.8269	0.7723
Etot=	0.9833	1.0545	1.0092	0.9304	0.9932

Source: own calculations

We have also divided the EU countries into two groups: 'rich' countries with a GDP above the EU average and 'poor' countries with a GDP below the EU average. The decomposition analysis for both groups revealed a remarkable disparity. Rich countries contributed significantly to the reduction in energy consumption, with a decrease of 23.55 million tonnes of oil equivalent (2.1%) over the whole study period. On the other hand, poor countries with a more energy-intensive economic structure experienced a slight increase of 0.12 Mtoe (0.04%). The detailed results of the additive and multiplicative decomposition for both rich and poor countries over the period 1998-2018 are presented in Table 4, while Figure 1 graphically illustrates the result of the additive decomposition of energy consumption for these two groups.

Table 4. Decomposition - breakdown of energy consumption by GDP for rich and poor countries (1998-2018)

	Additive decomposition		**Multiplicative decomposition**	
	Higher-income countries	**Lower-income countries**	**Higher-income countries**	**Lower-income countries**
	1998-2018		**1998-2018**	
Δ Eact=	-13.5081	344.8185	0.9875	3.0081
Δ Estr=	-295.2060	11.4158	0.7597	1.0371
Δ Eint=	285.1637	-356.1140	1.3000	0.3207
Δ Etot=	-23.5500	0.1200	0.9783	1.0004

Source: own calculations

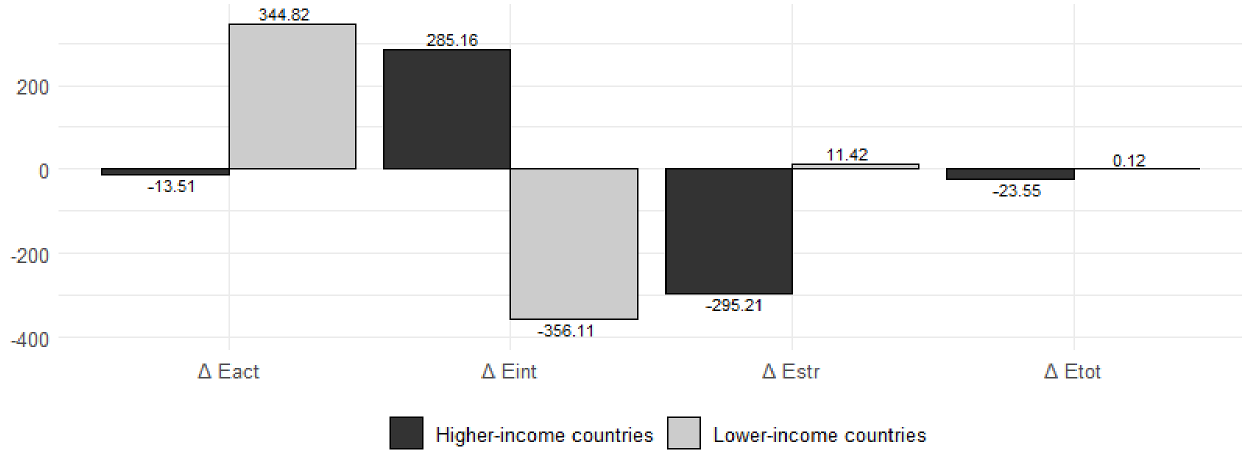


Figure 1. Comparison of higher-income and lower-income countries in terms of energy consumption (additive decomposition)
Source: own processing

In addition, Figure 2 provides an overview of the breakdown of energy consumption for each EU country over the period 1998-2018. Notable decreases in energy consumption were observed in Germany (-30.41 million toe), Italy (-11.05 million toe) and Romania (-7.19 million toe). Conversely, significant increases were recorded in Spain (+20.72 Mtoe), Poland (+9.4 Mtoe) and Austria (+4.14 Mtoe). Table 5 colour codes countries with decreasing energy consumption (green) and countries with increasing energy consumption (red) to visually distinguish the two trends.

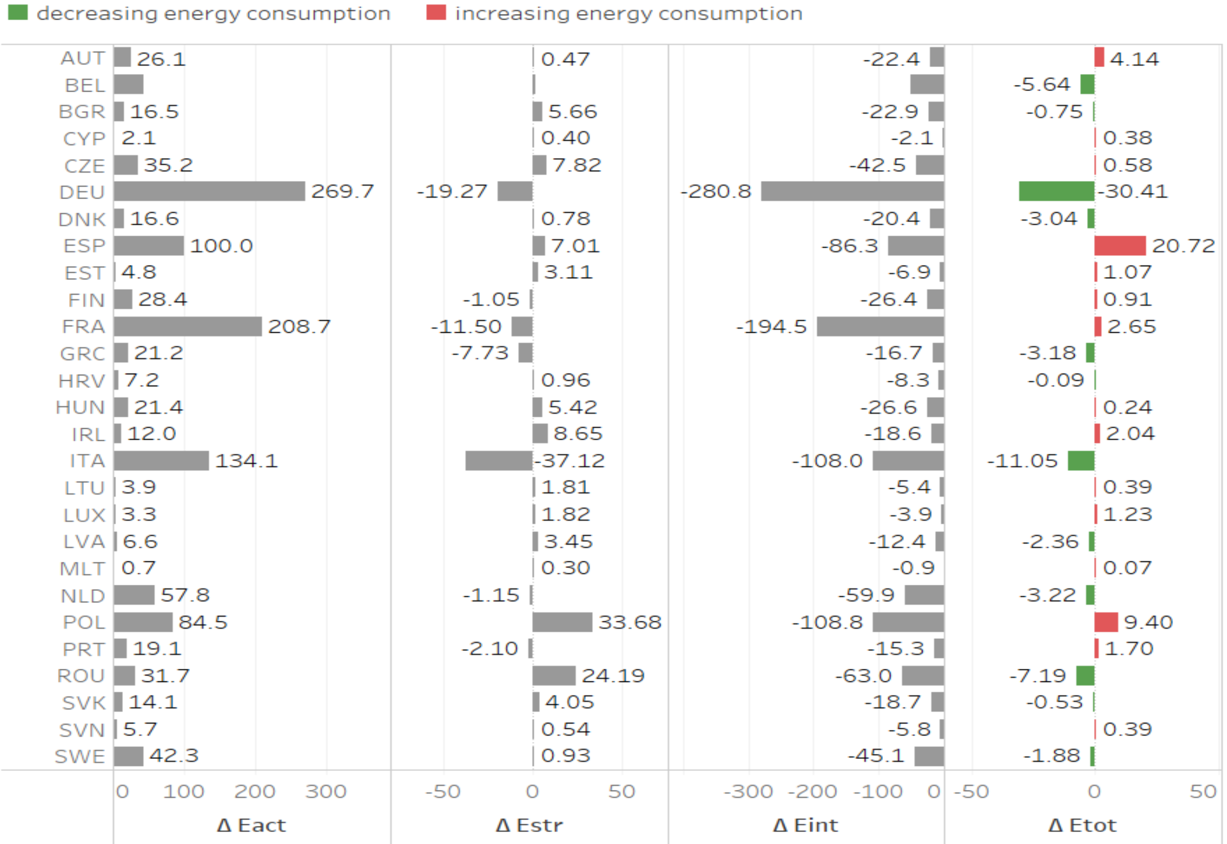


Figure 2. Additive decomposition - breakdown of energy consumption in individual EU countries (1998-2018)
Source: own calculations

Decomposition analysis of greenhouse gas emissions production

The production of greenhouse gas emissions is closely linked to energy consumption, which is mainly driven by the combustion of fossil fuels. This section of the analysis focuses on the decomposition of GHG emissions from GDP, using both additive and multiplicative decomposition methods. The analysis examines the effects of aggregate activity, sectoral structure and emission intensity.

First, the breakdown of GHG emissions within the EU over the entire observation period and in five-year periods is analysed. As shown in Table 5, the EU countries achieved an overall reduction in GHG emissions of 722.85 Mt over the reporting period. The main driving force behind this reduction was total activity, while emission intensity played a crucial role in reducing emissions. At the beginning of the observation period (1998-2003), greenhouse gas emissions increased by 60.44 million tonnes. However, in the following periods a decrease in emissions production was observed. A reduction of 201.5 million tonnes of greenhouse gas emissions was achieved between 2003 and 2008, followed by a remarkable decrease of 494.24 million tonnes between 2008 and 2013. Towards the end of the period (2013-2018), this reduction reached 87.55 million tonnes of GHG emissions. The growing emphasis on reducing the emission intensity of the EU's economic activities contributed significantly to this positive trend.

Table 5. Additive decomposition - breakdown of greenhouse gas emissions

	1998-2018	1998-2003	2003-2008	2008-2013	2013-2018
Δ Eact=	3373986.6	943312.1	1220526.0	424512.1	898030.3
Δ Estr=	137883.5	23751.7	57439.3	29840.8	20094.1
Δ Eint=	-4234723.7	-906628.0	-1479466.0	-948588.4	-1005677.0
Δ Etot=	-722853.7	60435.6	-201501.0	-494235.5	-87552.8

Source: own calculations

The results of the multiplicative decomposition are in line with those of the additive decomposition. Over the whole observation period, emissions decreased by 17.11%. In the first phase of the review, greenhouse gas emissions increased by 1.4%. However, in subsequent years, the data show a decrease, with reductions of 4.70% from 2003 to 2008, 12.10% from 2008 to 2013 and 2.44% from 2013 to 2018. Within each monitored period, the effectiveness of the emission intensity reduction proved to be a decisive factor in the reduction of greenhouse gas emissions. The results of the multiplicative decomposition of GHG emissions in relation to GDP for the whole observation period and for individual time intervals are presented in Table 6.

Table 6. Multiplicative decomposition - breakdown of greenhouse gas emissions

	1998-2018	**1998-2003**	**2003-2008**	**2008-2013**	**2013-2018**
Eact=	2.4014	2.4052	2.4055	2.4048	2.4055
Estr=	1.0365	0.5219	0.5643	0.4682	0.5386
Eint=	0.3330	0.8081	0.7021	0.7806	0.7530
Etot=	0.8289	1.0143	0.9530	0.8790	0.9756

Source: own calculations

Similar to the analysis of energy consumption, we compared the GHG emissions situation in rich and poor countries as a function of GDP level. Both groups showed improvements, but rich countries made more significant progress, reducing GHG emissions by 622.35 million tonnes (19.88%) over the whole period. In contrast, poor countries saw their emissions fall by 100.50 million tonnes (9.19%). The detailed results of this analysis are presented in Table 7 and Figure 3.

Table 7. Decomposition - breakdown of greenhouse gas emissions by GDP for rich and poor countries (1998-2018)

	Additive decomposition		Multiplicative decomposition	
	Higher-income countries	**Lower-income countries**	**Higher-income countries**	**Lower-income countries**
	1998-2018		**1998-2018**	
Δ Eact=	-35293.4550	1143955.0000	0.9875	2.9978
Δ Estr=	-536880.3700	28435.2400	0.8260	1.0277
Δ Eint=	-50176.4160	-1272894.0000	0.9823	0.2948
Δ Etot=	-622350.2400	-100503.0000	0.8012	0.9081

Source: own calculations

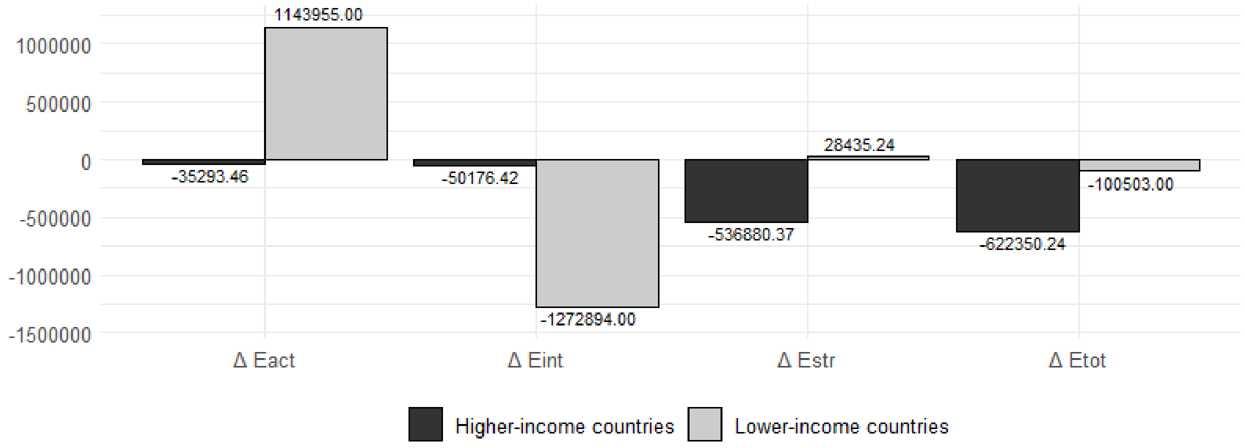
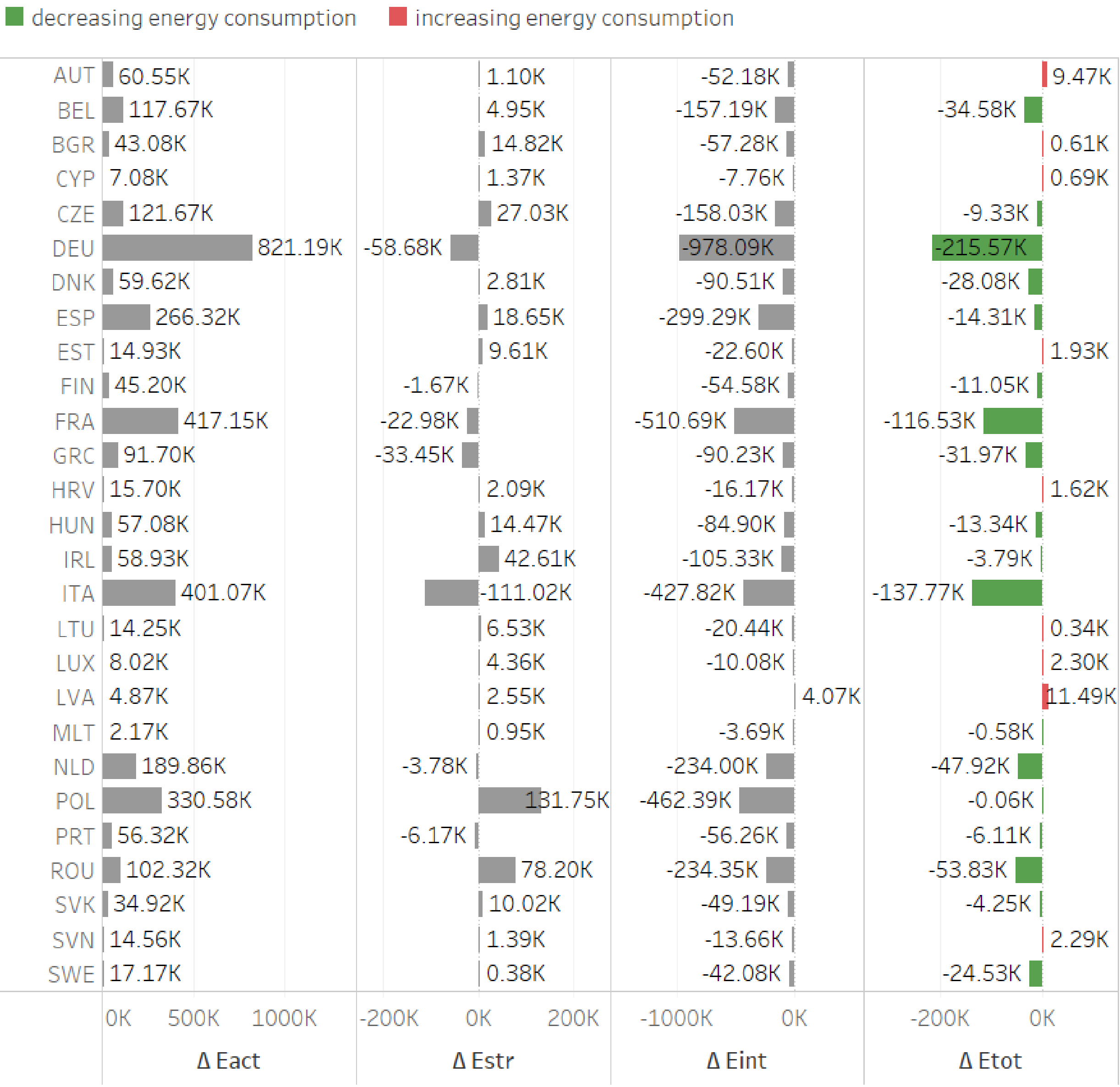


Figure 3. Comparison of higher-income and lower-income countries in terms of greenhouse gas emissions (additive decomposition)
Source: own processing

Figure 4 provides a detailed view of the GHG emissions production of individual EU countries. Throughout the reporting period, the countries with the largest reductions in greenhouse gas emissions are Germany (-215.57 Mt), Italy (-137.77 Mt) and France (-116.53 Mt). These reductions can be attributed to the composition of their energy mix, with Germany relying heavily on renewable energy sources and France making extensive use of low-carbon nuclear energy. On the other hand, Lithuania ranked last with an increase in emissions of 11.49 million tons, followed by Austria (increase of 9.47 million tons) and Luxembourg (2.30 million tons). The results of the additive decomposition of GHG emissions by GDP for each country are shown in Table 8, with countries showing a decrease in GHG emissions highlighted in green and countries showing an increase highlighted in red.



Note: K - Thousands

Figure 4. Additive decomposition - breakdown of greenhouse gas emissions in individual EU countries (1998-2018)
Source: own calculations

5. Discussion

Analysing energy consumption and GHG emissions in the European Union (EU) over the period considered (1998-2018) revealed remarkable trends and disparities between Member States. In particular, energy consumption showed a reduction in the period 2008-2013, with a significant decrease of 7%, followed by a more moderate decrease of 0.7% in the period 2013-2018. Wealthier countries contributed significantly to this reduction with a decrease of 2.1%. Poorer countries experienced a slight increase of 0.04%.

These findings are consistent with various academic contributions on the factors influencing energy intensity, emitting and reducing it. The impact of economic growth, capital intensity and energy prices on energy intensity was highlighted by Löschel et al. (Löschel et al., 2015). Achour & Belloumi (2016) emphasised the key role of energy intensity in reducing energy consumption. Factors such as economic output and transport intensity have a positive impact.

On the other hand, with an impressive total reduction of 722.85 million tonnes over the entire monitoring period, greenhouse gas emissions showed an overall positive trend. The most significant reduction occurred between 2008 and 2013, when emissions fell by 494.24 million tonnes. This was followed by a further reduction of 87.55 million tonnes up to 2018. Rich countries showed a stronger improvement, achieving a 19.88% reduction in GHG emissions, while poorer countries achieved a 9.19% reduction over the study period. These results are in line with (Chen et al., 2018), who highlighted the significant influence of energy intensity and GDP on CO_2 emissions in OECD countries, highlighting the opposite directions and greater weight of technical factors. Similarly, Mohmmed et al. (2019) identified population, energy intensity and various socioeconomic factors as influences on CO_2 emissions, with a significant increase predicted by 2030. Ortega-Ruiz et al. (2020) and Wang et al. (2021) both highlighted the role of per capita income and energy intensity in CO_2 emissions, with developed countries demonstrating a stronger impact of energy intensity on emissions.

While wealthier countries may appear to perform better, it should be noted that these countries often import goods and services that are energy-intensive to produce from other countries. This effectively offshores the environmental impacts associated with their consumption. This approach can give the appearance of reduced energy consumption within their borders, while shifting the environmental burden elsewhere.

This practice, known as 'carbon leakage' or 'embodied energy consumption' (Meunier et al., 2014; Moreau & Vuille, 2018), means that while direct energy consumption within a wealthier country may appear reduced, the energy embedded in imported goods and services often contributes to the energy consumed by exporting, typically poorer, countries. As a result, the overall environmental impact isn't reduced - it's just shifted across borders.

Therefore, while richer countries may show reductions in domestic energy consumption and CO_2 emissions, this observation could be influenced by their shift towards less energy and carbon-intensive activities domestically and reliance on imports that have the energy and carbon burden of production. This phenomenon underlines the importance of a holistic approach to environmental accounting, taking into account the whole supply chain and the global impact of consumption.

In addition, further efforts should be made in the form of political and financial incentives for industry to focus on finding technologies to reduce energy intensity or to increase the use of alternative energy sources (renewables) and reduce the use of fossil fuels (Chovancová et al., 2021; Petruška et al., 2022; Stefko et al., 2021). In addition, each country should cooperate with various international organisations to achieve the global goal of reducing CO_2 emissions (Chontanawat et al., 2020). It is also necessary to see a wide range of indicators of economic growth in the context of the need for an absolute reduction in the use of sources and the elimination of emissions, which is necessary to mitigate the climate crisis and strive for sustainability. In policy and research agendas, improving resource and energy efficiency appears as a key strategy to decouple economic growth from environmental pressures and impacts (Chovancová & Tej, 2020; Chovancová & Vavrek, 2020; OECD, 2019; Parrique et al., 2019; UNEP-IRP, 2019; Vavrek & Chovancova, 2016).

To mitigate carbon leakage, the introduction of carbon taxes should be considered. Carbon taxes act as an economic instrument, putting a price on carbon emissions and creating a financial incentive for both industry and consumers to reduce their carbon footprint. By internalising the cost of carbon emissions, these taxes encourage a shift towards cleaner technologies and practices, while generating revenue that can be reinvested in sustainable initiatives and renewable energy projects.

6. Conclusion with policy implications

The objective of this analysis was to examine the factors influencing energy consumption and greenhouse gas emissions in the European Union (EU) using the IDA and LMDI methodologies. The results show that the EU has made significant progress in reducing greenhouse gas emissions and energy consumption, thus making steady progress towards its long-term commitments to resource efficiency and climate change mitigation. However, progress has not been uniform across all EU countries, as it varies according to their unique economic structures, resource bases, and other factors that affect their ability to reduce energy consumption and emissions.

Over the period from 1998 to 2018, the reduction in EU GHG emissions was mainly driven by the significant contribution of the emission intensity reduction effect. This factor also had a positive impact on the reduction of energy consumption. However, an important driver for both variables was the level of economic activity in each country, which contributed to their increase. The role of the economic structure was found to be relatively marginal, but had a positive influence.

In addition, the analysis revealed notable differences in the approaches taken by different EU countries. In general, countries with above-average GDP have been more successful in reducing energy consumption and greenhouse gas emissions than countries with GDP below the EU average. This discrepancy can be attributed to different economic structures, with wealthier countries being more service-oriented (and less emission-intensive), while poorer countries, especially those from the former Eastern bloc, tended to be more production-oriented, resulting in higher energy and carbon intensity.

The EU has made significant progress in reducing emissions and energy consumption, reflecting its commitment to climate action and resource efficiency in line with its global commitments such as Agenda 2030 and the Paris Agreement (Vavrek & Chovancová, 2020). However, the results show uneven performance across Member States, influenced by economic structures and resource endowments. As the EU continues on its path towards climate neutrality, several policy implications emerge:

- The EU should adopt a flexible and tailored approach to address the different challenges faced by individual Member States. Recognising that the drivers of energy consumption and emissions differ from country to country, specific policies and support mechanisms should be designed to suit the unique context of each country.
- To bridge the gap between richer and poorer EU countries in reducing energy consumption and emissions, a focus on technology transfer and green innovation is essential. Promoting the uptake of sustainable technologies, renewable energy sources, and energy-efficient practices can accelerate progress in reducing emissions.
- Encouraging cooperation and knowledge sharing among EU countries can promote collective learning and best practices. Facilitating the transfer of expertise from more advanced Member States to those facing challenges can accelerate the transition to sustainable energy and lower emissions.

The decomposition analysis used in this study provides valuable insights into the drivers of energy consumption and emissions. However, the approach simplifies complex interactions and may miss certain nuances in the relationships between variables.

Future research could conduct in-depth case studies of individual EU countries to examine more comprehensively the factors influencing their energy consumption and emission reduction efforts. Similarly, sectoral analysis could be undertaken to examine the variations in energy use and emissions across different sectors.

References

Ahmad, M., Ahmed, Z., Gavurova, B., & Oláh, J. (2022). Financial risk, renewable energy technology budgets, and environmental sustainability: is going green possible? *Frontiers in Environmental Science*, 10. https://doi.org/10.3389/fenvs.2022.909190

Achour, H., & Belloumi, M. (2016). Decomposing the influencing factors of energy consumption in Tunisian transportation sector using the LMDI method. *Transport Policy*, *52*, 64-71. https://doi.org/10.1016/J.TRANPOL.2016.07.008

Androniceanu, A., & Georgescu, I. (2023). The impact of CO2 emissions and energy consumption on economic growth: a panel data analysis. *Energies*, 16(3), 1342. https://doi.org/10.3390/en16031342

Ang, B. W. (2015). LMDI decomposition approach: a guide for implementation. *Energy Policy*, 86, 233-238. https://doi.org/10.1016/j.enpol.2015.07.007

Bhattacharyya, S. C., & Matsumura, W. (2010). Changes in the GHG emission intensity in EU-15: Lessons from a decomposition analysis. *Energy*, 35(8), 3315-3322. https://doi.org/10.1016/J.ENERGY.2010.04.017

Boqiang, L., & Liu, K. (2017). Using LMDI to Analyze the Decoupling of Carbon Dioxide Emissions from China's Heavy Industry. *Sustainability*, 9(7), 1198. https://doi.org/10.3390/SU9071198

Cansino, J. M., Román, R., & Ordóñez, M. (2016). Main drivers of changes in CO2 emissions in the Spanish economy: A structural decomposition analysis. *Energy Policy*, 89, 150-159. https://doi.org/10.1016/J.ENPOL.2015.11.020

Gavurova, B., Megyesiova, S., & Hudak, M. (2021). Green growth in the OECD countries: A multivariate analytical approach. *Energies*, 14(20), 6719. https://doi.org/10.3390/en14206719

Chen, B., Li, J. S., Zhou, S. L., Yang, Q., & Chen, G. Q. (2018). GHG emissions embodied in Macao's internal energy consumption and external trade: Driving forces via decomposition analysis. *Renewable and Sustainable Energy Reviews*, 82, 4100-4106. https://doi.org/10.1016/J.RSER.2017.10.063

Chen, J., Wang, P., Cui, L., Huang, S., & Song, M. (2018). Decomposition and decoupling analysis of CO2 emissions in OECD. *Applied Energy*, 231, 937-950. https://doi.org/10.1016/J.APENERGY.2018.09.179

Chen, J., Xu, C., Wu, Y., Li, Z., & Song, M. (2021). Drivers and trajectories of China's renewable energy consumption. *Annals of Operations Research*, 313, 441-459. https://doi.org/10.1007/s10479-021-04131-y

Chong, C. H., Tan, W. X., Ting, Z. J., Liu, P., Ma, L., Li, Z., & Ni, W. (2019). The driving factors of energy-related CO2 emission growth in Malaysia: The LMDI decomposition method based on energy allocation analysis. *Renewable and Sustainable Energy Reviews*, 115, 109356. https://doi.org/10.1016/J.RSER.2019.109356

Chontanawat, J., Wiboonchutikula, P., & Buddhivanich, A. (2020). An LMDI decomposition analysis of carbon emissions in the Thai manufacturing sector. *Energy Reports*, 6, 705-710. https://doi.org/10.1016/J.EGYR.2019.09.053

Chovancová, J., Litavcová, E., & Shevchenko, T. (2021). Assessment of the relationship between economic growth, energy consumption, carbon emissions and renewable energy sources in the V4 countries. *Journal of Management and Business: Research and Practice*, 13(2). https://journalmb.eu/JMB/article/download/27/26

Chovancová, J., & Tej, J. (2020). Decoupling economic growth from greenhouse gas emissions: the case of the energy sector in V4 countries. *Equilibrium*, 15(2), 235-251. https://doi.org/10.24136/eq.2020.011

Dai, X.-w., Sun, Z., & Müller, D. (2021). Driving factors of direct greenhouse gas emissions from China's pig industry from 1976 to 2016. *Journal of Integrative Agriculture*, 20(1), 319-329. https://doi.org/10.1016/S2095-3119(20)63425-6

Drastichová, M. (2017). Decomposition Analysis of the Greenhouse Gas Emissions in the European Union. *Problemy Ekorozwoju/Problems of Sustainable Development*, 12(2), 27-35. https://ssrn.com/abstract=3000380

Du, G., Sun, C., Ouyang, X., & Zhang, C. (2018). A decomposition analysis of energy-related CO2 emissions in Chinese six high-energy intensive industries. *Journal of Cleaner Production*, 184, 1102-1112. https://doi.org/10.1016/J.JCLEPRO.2018.02.304

Habimana Simbi, C., Lin, J., Yang, D., Ndayishimiye, J. C., Liu, Y., Li, H., Xu, L., & Ma, W. (2021). Decomposition and decoupling analysis of carbon dioxide emissions in African countries during 1984–2014. *Journal of Environmental Sciences*, 102, 85-98. https://doi.org/10.1016/J.JES.2020.09.006

IPCC (2021). Climate Change 2021: The Physical Science Basis. https://www.ipcc.ch/report/sixth-assessment-report-working-group-i/

Istudor, N., Dinu, V., & Nitescu, D.C. (2021). Influence Factors of Green Energy on EU Trade. *Transformations in Business & Economics*, Vol. 20, No 2 (53), pp.116-130.

Jeong, K., & Kim, S. (2013). LMDI decomposition analysis of greenhouse gas emissions in the Korean manufacturing sector. *Energy Policy*, 62, 1245-1253. https://doi.org/10.1016/J.ENPOL.2013.06.077

Karmellos, M., Kopidou, D., & Diakoulaki, D. (2016). A decomposition analysis of the driving factors of CO2 (Carbon dioxide) emissions from the power sector in the European Union countries. *Energy*, 94, 680-692. https://doi.org/10.1016/J.ENERGY.2015.10.145

Kijewska, A., & Bluszcz, A. (2016). Analysis of greenhouse gas emissions in the European Union member states with the use of an agglomeration algorithm. *Journal of Sustainable Mining*, 15(4), 133-142. https://doi.org/10.1016/J.JSM.2017.02.001

Kisielewicz, J., Sobey, M., Verstraeten, Y., Marino, A., Lavric, L., Voigt, S., & Tallat-Kelpsaite, J. (2019). Decomposition analysis of the changes in GHG emissions in the EU and Member States. Final report. https://doi.org/10.2834/397144

Löschel, A., Pothen, F., & Schymura, M. (2015). Peeling the onion: analyzing aggregate, national and sectoral energy intensity in the European Union. *Energy Economics*, 52, 63-75. https://doi.org/10.1016/j.eneco.2015.09.004

Luo, Y., Zeng, W., Hu, X., Yang, H., & Shao, L. (2021). Coupling the driving forces of urban CO2 emission in Shanghai with logarithmic mean Divisia index method and Granger causality inference. *Journal of Cleaner Production*, 298, 126843. https://doi.org/10.1016/J.JCLEPRO.2021.126843

Meunier, G., Ponssard, J. P., & Quirion, P. (2014). Carbon leakage and capacity-based allocations: Is the EU right? *Journal of Environmental Economics and Management*, 68(2), 262-279. https://doi.org/10.1016/J.JEEM.2014.07.002

Mohmmed, A., Li, Z., Olushola Arowolo, A., Su, H., Deng, X., Najmuddin, O., & Zhang, Y. (2019). Driving factors of CO2 emissions and nexus with economic growth, development and human health in the Top Ten emitting countries. *Resources, Conservation and Recycling*, 148, 157-169. https://doi.org/10.1016/J.RESCONREC.2019.03.048

Moreau, V., & Vuille, F. (2018). Decoupling energy use and economic growth: Counter evidence from structural effects and embodied energy in trade. *Applied Energy*, 215, 54-62. https://doi.org/10.1016/J.APENERGY.2018.01.044

Mousavi, B., Lopez, N. S. A., Biona, J. B. M., Chiu, A. S. F., & Blesl, M. (2017). Driving forces of Iran's CO2 emissions from energy consumption: An LMDI decomposition approach. *Applied Energy*, 206, 804-814. https://doi.org/10.1016/J.APENERGY.2017.08.199

Nejat, P., Jomehzadeh, F., Taheri, M. M., Gohari, M., & Muhd, M. Z. (2015). A global review of energy consumption, CO2 emissions and policy in the residential sector (with an overview of the top ten CO2 emitting countries). *Renewable and Sustainable Energy Reviews*, 43, 843-862. https://doi.org/10.1016/J.RSER.2014.11.066

Nordhaus, W. (2013). The climate casino: Risk, uncertainty, and economics for a warming world. Yale University Press.

OECD (2019). Global material resources outlook to 2060: economic drivers and environmental consequences (OECD). https://doi.org/10.1787/9789264307452-en

Ortega-Ruiz, G., Mena-Nieto, A., & García-Ramos, J. E. (2020). Is India on the right pathway to reduce CO2 emissions? Decomposing an enlarged Kaya identity using the LMDI method for the period 1990–2016. *Science of The Total Environment*, 737, 139638. https://doi.org/10.1016/J.SCITOTENV.2020.139638

Parrique, T., Barth, J., Briens, F., Kerschner, C., Kraus-Polk, A., Kuokkanen, A., & Spangenberg, J.H. (2019). Decoupling Debunked. Evidence and Arguments Against Green Growth as a Sole Strategy for Sustainability. European Environmental Bureau.

Petruška, I., Litavcová, E., & Chovancová, J. (2022). Impact of Renewable Energy Sources and Nuclear Energy on CO2 Emissions Reductions – The Case of the EU Countries. *Energies*, 15(24), 9563. https://doi.org/10.3390/EN15249563

Qi, T., Weng, Y., Zhang, X., & He, J. (2016). An analysis of the driving factors of energy-related CO2 emission reduction in China from 2005 to 2013. *Energy Economics*, 60, 15-22. https://doi.org/10.1016/J.ENECO.2016.09.014

Reyers, B., Stafford-Smith, M., Erb, K. H., Scholes, R. J., & Selomane, O. (2017). Essential Variables help to focus Sustainable Development Goals monitoring. *Current Opinion in Environmental Sustainability*, 26-27, 97-105. https://doi.org/10.1016/J.COSUST.2017.05.003

Román, R., Cansino, J. M., & Rodas, J. A. (2018). Analysis of the main drivers of CO2 emissions changes in Colombia (1990–2012) and its political implications. *Renewable Energy*, 116, 402-411. https://doi.org/10.1016/J.RENENE.2017.09.016

Simionescu, M., Szeles, M. R., Gavurova, B., & Mentel, U. (2021). The impact of quality of governance, renewable energy and foreign direct investment on sustainable development in cee countries. *Frontiers in Environmental Science*, 9, 765927. https://doi.org/10.3389/fenvs.2021.765927

Simionescu, M., Strielkowski, W., & Gavurova, B. (2022). Could quality of governance influence pollution? Evidence from the revised Environmental Kuznets Curve in Central and Eastern European countries. Energy Reports, 8, 809-819. https://doi.org/10.1016/j.egyr.2021.12.031

Skare, M., Gavurova, B., & Kovac, V. (2023). Investigation of selected key indicators of circular economy for implementation processes in sectorial dimensions. *Journal of Innovation & Knowledge*, 8(4), 100421. https://doi.org/10.1016/j.jik.2023.100421

Škare, M., Gavurova, B., & Porada-Rochon, M. (2024). Digitalization and carbon footprint: Building a path to a sustainable economic growth. *Technological Forecasting and Social Change*, 199, 123045. https://doi.org/10.1016/j.techfore.2023.123045

Soltes, V. & Gavurova, B. (2015). Modification Of Performance Measurement System In The Intentions Of Globalization Trends. *Polish Journal of Management Studies*, 11(2), 160-170.

Stefko, R., Gavurova, B., Kelemen, M., Rigelsky, M., & Ivankova, V. (2021). Relationships between Renewable Energy and the Prevalence of Morbidity in the Countries of the European Union: A Panel Regression Approach. *International Journal of Environmental Research and Public Health*, 18(12), 6548. https://doi.org/10.3390/ijerph18126548

Tkacova, A., & Gavurova, B. (2023). Economic sentiment indicators and their prediction capabilities in business cycles of EU countries. *Oeconomia Copernicana*, 14(3), 977-1008. https://doi.org/10.24136/oc.2023.029

Tyagi, S., Tiwari, S., Mishra, A., Hopke, P. K., Attri, S. D., Srivastava, A. K., & Bisht, D. S. (2016). Spatial variability of concentrations of gaseous pollutants across the National Capital Region of Delhi, India. *Atmospheric Pollution Research*, 7(5), 808-816. https://doi.org/10.1016/J.APR.2016.04.008

UNEP-IRP (2019). Global Resources Outlook 2019. Natural Resources for the Future We Want.

Vavrek, R., & Chovancová, J. (2020). Energy performance of the European Union Countries in terms of reaching the European energy union objectives. *Energies*, 13(20), 5317. https://doi.org/10.3390/en13205317

Vavrek, Roman, & Chovancova, J. (2016). Decoupling of Greenhouse Gas Emissions from Economic Growth in V4 Countries. Procedia Economics and Finance, 39, 526-533. https://doi.org/10.1016/s2212-5671(16)30295-7

Wang, M., & Feng, C. (2018). Using an extended logarithmic mean Divisia index approach to assess the roles of economic factors on industrial CO2 emissions of China. *Energy Economics*, 76, 101-114. https://doi.org/10.1016/j.eneco.2018.10.008

Wang, Q., Li, R., Su, M., & Wang, S. (2022). Extreme events and carbon emissions: What we could learn from decomposition of national- and sector-carbon emission. *Energy Strategy Reviews*, 44, 100978. https://doi.org/10.1016/J.ESR.2022.100978

Wang, W., Liu, X., Zhang, M., & Song, X. (2014). Using a new generalized LMDI (logarithmic mean Divisia index) method to analyze China's energy consumption. *Energy*, 67, 617-622. https://doi.org/10.1016/J.ENERGY.2013.12.064

Wang, Z., Ben Jebli, M., Madaleno, M., Doğan, B., & Shahzad, U. (2021). Does export product quality and renewable energy induce carbon dioxide emissions: Evidence from leading complex and renewable energy economies. *Renewable Energy*, 171, 360-370. https://doi.org/10.1016/J.RENENE.2021.02.066

Xu, J. H., Fan, Y., & Yu, S. (2014). Energy conservation and CO2 emission reduction in China's 11th Five-Year Plan: a performance evaluation. *Energy Economics*, 46, 348-359. https://doi.org/10.1016/j.eneco.2014.10.013

Xu, J., Zhou, M., & Li, H. (2018). The drag effect of coal consumption on economic growth in China during 1953–2013. *Resources, Conservation and Recycling*, 129, 326-332. https://doi.org/10.1016/J.RESCONREC.2016.08.027

Xu, X. Y., & Ang, B. W. (2013). Index decomposition analysis applied to CO2 emission studies. *Ecological Economics*, 93, 313-329. https://doi.org/10.1016/J.ECOLECON.2013.06.007

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