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## Exploring the relationship between CO<sub>2</sub>, economic growth, and other influential factors in the European Union

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**Abstract.** The rapid development of the economy impacts environmental degradation, where climate change is the major issue. Despite all efforts of international organisations, governments, businesses, and ordinary citizens, the problem cannot be successfully managed. The main objective of the study was to test the relationship between CO<sub>2</sub> and economic growth and two other indicators. In addition, the share of renewable energy and energy efficiency level indicators was included to testing environmental investments in the energy sector. The study used a sample of 23 EU member states over the period 2009-2023. Data were obtained from Eurostat and normalised using the mean-standardisation approach. Regression analysis was used to examine the relationships among the selected variables. The regression analysis confirmed that GDP and renewable energy consumption had positive effects on CO<sub>2</sub> emissions, whereas energy intensity had no statistically significant effect. To more deeply reveal regional structural development tendencies, the chosen sample was categorized into three groups using K-means clustering. Despite efforts to delink economic growth

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from CO<sub>2</sub> emissions, the findings indicate that this objective has not yet been achieved. The study emphasised the need for stronger political commitment and more effective strategies to achieve meaningful progress in the emission-growth delinking process. The analysis covered a specific period and the *ceteris paribus* assumption may not hold fully due to the presence of other factors. Further examination of additional explanatory factors may also provide new insights and policy implications.

**Keywords:** carbon dioxide, gross domestic product, renewable energy, energy intensity, European Union

**JEL Classification:** Q42, Q43, Q53, O52.

## 1. INTRODUCTION

The global challenge of combating climate change has made the transition to a green economy an urgent priority internationally, with the European Union (EU) playing a critical role. Climate neutrality by 2050 means that EU countries must achieve net-zero greenhouse gas emissions, mainly by reducing emissions in the energy sector, replacing highly polluting energy sources such as coal and gas with renewable energy, investing in technological improvements and protecting the environment. The EU is at the forefront of this transformation of the energy sector, implementing ambitious policies and goals to reduce emissions and increase the share of renewable energy (European Commission, 2022). The EU plays a critical role in the decarbonization of the economy that is driven by the urgent need to prevent climate change and maintain a liveable planet for future generations. At the core of this transition is the energy sector that is responsible for 75% of greenhouse gas (GHG) emissions. To achieve climate neutrality, the energy sector must transition from fossil fuel to renewable energy sources. This transformation is impacted by multiple factors: regulatory and policy initiatives, technological limitations, innovation, economic constraints, geopolitical challenges and social acceptance issues. This study focuses on the EU's efforts to transform the energy sector in alignment with climate neutrality goals and analysis of key factors influencing this transformation.

Academic research related to the relationship between CO<sub>2</sub> and GDP in the EU covers a wide range of topics, from an in-depth analysis of policy systems and objectives, issues related to the implementation of renewable energy and energy efficiency, the role of green financing, and analysis of various factors such as geopolitical issues. There is a wide range of studies that analyse the factors influencing CO<sub>2</sub> emissions. Two main approaches can be distinguished. The initial group, based on the work of Grossman & Krugman since its publication in the 1990s, examines the validity of the ECG (Stern, 1998; Lapinskienė et al., 2014; Nazir et al., 2018; Akar et al., 2025). The second group can be divided into various subgroups, for example, focussing on energy consumption or examining various other factors, such as the relationship between fossil fuels and renewable resources, as well as focussing on other factors, such as global trade and other factors (Shahnazi & Shabani, 2021; Cao et al., 2022; Chen et al., 2022; Hasanov et al., 2024; Mukhtarov et al., 2024; Štreimikienė, 2024). For such studies, researchers use CO<sub>2</sub> or GHG as a reliable dependent indicator. The transition to renewable energy systems is crucial to combating climate change and achieving sustainable development. Therefore, there is a wealth of literature that examines the impact of non-renewable energy consumption, renewable energy consumption, and per capita income on CO<sub>2</sub> emissions.

Recent studies have examined carbon dioxide emissions and GDP and the transformation of the energy sector from multiple perspectives, applying variations of regression analysis to different regions and time intervals (Balsobre-Lorente et al., 2018; Murshed et al., 2022; Chen et al., 2022; Hassan et al., 2024;

Gatto et al., 2024; Kharazishvili et al., 2025; Mishchuk et al., 2023; Rao et al., 2024). This line of research requires continuous testing to capture new insights and monitor the green transition. The importance of renewable energy and energy efficiency is emphasised by international agencies (United Nations, 2015). Renewable energy technologies are the most widely used technologies for achieving zero carbon dioxide emissions. The contribution of this study is to verify selected empirical data, which together help to monitor how economic and energy factors affect carbon dioxide emissions in selected countries.

The article follows the research directions by testing specific factors for the chosen set of data. Objective - to test the relationship between CO<sub>2</sub> and GDP including additional factors in the EU level. This article leverages a combination of statistical and econometric analyses, such as gathering and systemizing theoretical material, statistical analysis of secondary data, and regression analysis.

## **2. LITERATURE REVIEW**

The analysis of environmental indicators and economic growth has a long history of research. In 1991, Grossman and Krueger, based on Kuznets' analysis of relationships, presented a study on the possible environmental impact of the North American Free Trade Agreement. Kuznets (1955) was the first to present the relationship between two indicators (he studied GDP and income inequality) in the form of an inverted U. Recently, this relationship has been reinterpreted in environmental economics literature as ECF. In the last 30 years, this type of research has become popular, and the ECG model is used to explain economic growth and its impact on the environment. Scientists have also identified the GDP level at which pollution begins to decline (Beckerman, 1992; Grossman & Krueger, 1991, 1995; Holtz-Eakin & Selden, 1995). Despite its widespread use, the ECA system has been criticized for its limitations, as noted by Dinda (2004; 2006) and Brock & Taylor (2010). Since then, this type of analysis has become popular and is used to test various regions, periods, or specific industries. The main questions remain the same: what is the relationship between GDP and various indicators of environmental degradation, and at what turning points does environmental degradation begin to decline? (Stern, 1998; Apergis & Payne, 2009; Becerril Torres et al., 2025; Saboori & Sulaiman, 2013; Nazir et al., 2018; Akar et al., 2025).

In recent decades, most studies have been expanded to include other independent variables. The inclusion of other indicators makes such studies suitable for testing various factors. Some studies focus specifically on the energy industry, examining the impact of various types of indicators, including renewable energy sources, energy productivity, energy capacity, or other indicators related to the green transformation of this industry (Chen et al., 2022; Hassan et al., 2024; Plotnikova & Vienažindienė, 2025). There are many studies that test various factors in a single model, such as financial development, foreign direct investment, population density, level of industrialisation, etc (Balsalobre-Lorente et al., 2018; Shahnazi & Shabani, 2021; Cao et al., 2022; Hasanov et al., 2024; Vasylieva et al., 2025). The summaries are provided below.

Table 1

## Models used in research studies

Equation (model)	Data, Methods	Results	Authors (year)
Dependent - CO <sub>2</sub> ; independent variables - shares of exports and imports in gross domestic product; GDP; share of renewable energy consumption; total factor productivity.	1990 – 2018; 20 countries that rank highest in the Renewable Energy Country Attractiveness Index - set of developing and developed countries, which can serve as benchmarks of their renewable energy consumption models; panel time series methods.	The total factor productivity and the share of renewable energy consumption have a significant reduction in CO <sub>2</sub> emissions, while income, imports increase emissions.	Hasanov et al. (2024)
Dependent - CO <sub>2</sub> ; key explanatory variables: GDP, renewable energy share, energy intensity as well as control variables: technology, financial development.	2007–2021; EU-27 panel data, log regression analysis (advanced econometric techniques).	The renewable energy reduces emissions, while energy intensity increases them.	Arshad et al. (2025)
Dependent - CO <sub>2</sub> ; independent variables – GDP; renewable, non-renewable energy consumption; economic freedom; urbanisation.	Econometric model for EU countries 2000-2017.	The use of renewable energy had a negative impact on CO <sub>2</sub> emissions, and the relationship between economic freedom and CO <sub>2</sub> emissions was U-shaped.	Shahnazi & Shabani (2021)
Dependent - ecological footprint; independent variables - economic complexity, natural resources, consumption of renewable energy, and foreign direct investment.	1995–2017 118 countries, panel data vector autoregressive approach	A two-way causal relationship between foreign direct investment and ecological footprint, confirming the reciprocal effect of ecological footprint on renewable energy.	Rafei et al. (2022)
Dependent - CO <sub>2</sub> ; independent variables -renewable energy consumption; electricity consumption; economic growth; institutional quality; globalisation; stock market; financial development.	1985–2018 36 OECD countries; balanced panel data set.	By increasing REC, CO <sub>2</sub> emissions are reduced by approximately 0.65% in the long term and 0.45% in the short term.	Cao et al. (2022)
Analysis of the potential and efficiency of renewable energy sources', with a focus on solar, wind, hydroelectric, and green hydrogen technologies	27 EU countries and the UK between 2001-2021; comparative analysis, correlation analysis	Areas of surplus or shortage of renewable energy resources have been identified. Austria, Belgium, and Germany have made significant progress in all areas of renewable energy.	Hassan et al. (2024)
Dependent - CO <sub>2</sub> ; independent variables - renewable energy consumption per capita, non-renewable energy consumption per capita, GDP per capita	97 countries between 1995-2015; dynamic panel threshold regression model	The relationship between growth in renewable energy consumption and growth in CO <sub>2</sub> emissions per capita is significant and negative only if countries consume more renewable energy.	Chen et al. (2022)
Dependent - GHG; independent variables - GDP, renewable electricity consumption; trade openness; natural resource abundance; energy innovation	Germany, France, Italy, Spain, and the United Kingdom between 1985-2016; Panel least squares, correlation analysis	Renewable electricity consumption reduces CO <sub>2</sub> emissions.	Balsalobre-Lorente et al. (2018)

*Source:* compiled by the authors

An article analysing the dynamics of CO<sub>2</sub> and GDP in 11 countries since 1990 emphasises that a complex geopolitical situation is needed to decouple economic growth from CO<sub>2</sub> emissions. The confirmed

results support the Environmental Kuznets Curve in the sense that GDP per capita has grown while CO<sub>2</sub> emissions per capita have decreased (Ziemblińska et al., 2025). A study by Hassan et al. (2024) provided a detailed analysis of renewable energy capacity and production in 27 countries of the European Union and the United Kingdom from 2001 to 2021. Germany is the leader in renewable energy production, mainly due to significant advances in solar and wind energy technologies. France and Germany are also leaders in green hydrogen production. Hydropower remains an essential component of renewable energy production in countries with favourable geographical conditions, while solar and wind energy dominate overall production trends throughout the region. Hassan et al. (2024) conducted a comprehensive study mapping the European energy landscape in 2024. The authors stressed that Germany is a leader in producing renewable energy, especially developing solar and wind energy, as well as keeping leadership together with France in green hydrogen production. The authors emphasised that Germany is a leader in renewable energy production, particularly in the development of solar and wind energy, and, together with France, maintains its leadership in green hydrogen production. Countries with high energy consumption are investing more in renewable energy production. Murshed et al. (2022) examined the key factors that influence carbon dioxide productivity in seven countries from 2007 to 2018. The researchers combined renewable energy, economic growth, urbanisation, financial inclusion, and globalisation to test their impact on carbon dioxide productivity. The findings show that renewable energy consumption has a positive impact on carbon dioxide productivity. A study by Balsalobre-Lorente et al. (2018) provided evidence of how economic growth, renewable energy consumption, and natural resource abundance affect CO<sub>2</sub> emissions in five EU countries (France, Germany, Italy, Spain and the UK) from 1985 to 2016. The results of the study confirm that renewable energy consumption has a significant negative impact on CO<sub>2</sub> emissions. The results of the study show that increased economic activity leads to increased energy consumption and emissions, especially when renewable energy is not sufficiently deployed. Chen et al. (2022) examined the relationship between renewable energy consumption and CO<sub>2</sub> emissions in 97 countries from 1995 to 2015 using a dynamic panel regression model. The authors emphasised that there is a certain threshold at which renewable energy consumption significantly reduces CO<sub>2</sub> emissions per capita.

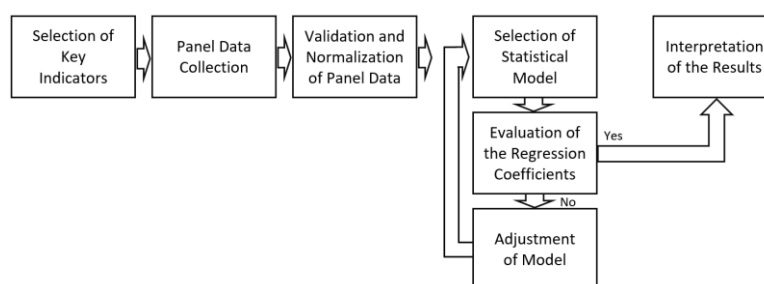
In general, the studies analysed underscore the crucial role of renewable energy in mitigating CO<sub>2</sub> emissions to achieve global sustainability goals. Renewable energy consumption has consistently been shown to significantly lower CO<sub>2</sub> emissions; however, the impact of economic growth on GHG is more complex and findings in multiple studies vary, suggesting that GDP growth has inconsistent impact on CO<sub>2</sub> emissions across markets. Furthermore, geopolitical factors, such as the Russia-Ukraine war, reveal the critical need for energy security and infrastructure protection to sustain renewable energy transitions. Collectively, these findings stress the need for targeted policies, regulation, and investments to promote renewable energy, manage external dependencies, and optimise carbon productivity, paving the way for a more sustainable and resilient global energy landscape.

Table 1 summarizes some of the studies, specifically from European economies, in the existing literature to identify the gaps and the methods and techniques that contribute to the existing knowledge (Balsalobre-Lorente et al., 2018; Shahnazi & Shabani, 2021; Cao et al., 2022; Chen et al., 2022; Hassan et al., 2024; Hasanov et al., 2024; Arshad et al., 2025). The existing literature also shows mixed results, which motivates us to continue the analysis by employing the selected indicators and a more recent dataset, and by enhancing the study's relevance for policymakers through the inclusion of a clustering method. Based on the relationship between economic growth and energy consumption (Kraft & Kraft, 1978) and the theoretical foundations of sustainable development, particularly the Environmental Kuznets Curve, this study aims to empirically investigate how GDP, the share of renewable energy, and energy intensity affect CO<sub>2</sub> emissions.

### 3. METHODOLOGY

For this empirical study, panel data was gathered from Eurostat to analyse the relationship between CO<sub>2</sub> emissions, renewable energy growth, energy intensity, and economic growth. For this research a panel model between-effects was estimated using the R programming environment.

In Figure 1 the steps of the analysis, the econometric estimation, and the process of evaluation and adjustment of the statistical model are presented.



**Figure 1. Approach of the Econometric Estimation**

*Source:* compiled by the authors

As outlined in Figure 1 as a first step panel data was collected from Eurostat. The time-series for the panel data observations used in the analysis is from 2009 to 2023. The EU countries used in the study are Malta, Ireland, Lithuania, Netherlands, Greece, Cyprus, Denmark, Austria, Belgium, Poland, France, Latvia, Luxembourg, Spain, Germany, Sweden, Italy, Slovakia, Czechia, Hungary, Portugal, Croatia, Slovenia, Bulgaria, Finland, Estonia, Romania. 27 countries plus the whole sample were doubled with the purpose of having a larger sample European Union – 27 countries (from 2020).

To achieve the set goal, the model presented below was used:

$$CO_{2,i} = \alpha + \beta_1 GDP_i + \beta_2 Renew_i + \beta_3 En\_intensity_i + \beta_4 D_{2009,i} + \beta_5 D_{2010,i} + \varepsilon_i \quad (1)$$

where  $i$  indexes' countries and  $\varepsilon_{it}$  – denotes normally distributed error term.

$CO_{2,i}$  – CO<sub>2</sub> (carbon dioxide) emissions measured in tonnes per capita.

$GDP_i$  – GDP (gross domestic product) per capita, a measure of a country's economic productivity, showing the total monetary value of all goods and services produced within the country's territory during a given year, divided by the number of inhabitants of that country. This indicator has been chosen as an indicator of economic growth.

$Renew_i$  – share of renewable energy in gross final energy consumption by sector (RENC). This indicator measures the share of renewable energy consumption in gross final energy consumption according to the Renewable Energy Directive. It is expressed as a percentage. Renewable energy is energy consumption from renewable sources, including hydroelectric, geothermal, wind, solar, biomass, and waste, measured in tonnes of equivalent oil per capita.

$En\_intensity_i$  – Energy Intensity (EN\_INTENSITY). According to Eurostat, energy intensity is an indicator that measures how much primary energy a country needs to produce one unit of economic output. Energy intensity=Gross inland energy consumption/GDP (kilogrammes of oil equivalent per 1000 EUR (kg/€ 000)).

$D_{2009,i}$  – Dummy for 2009 as controller for potential global shocks (financial crisis).

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For consistency, datasets were selected from Eurostat based on highly comparable standardised methodologies (Eurostat, 2025). To accurately analyse the relationships in the data, all indicators were converted to per capita metrics, ensuring that they are on a consistent scale. Using mixed levels, such as per capita for one indicator and total values for another, would distort comparisons and lead to misleading results in the regression analysis. All variables were averaged over the period 2009-2023. This approach captures the variation between countries.

The analysis used a panel model between-effects with random individual variation (country) to examine the determinants of CO<sub>2</sub> emissions between countries. In this specification, all variables were averaged over time for each country, so the estimation relies solely on between-country variation rather than within-country (overtime) changes. This approach captures structural differences between countries in their average levels of CO<sub>2</sub> emissions, GDP, share of renewable energy, and intensity of energy. The inclusion of year dummies for 2009 and 2010 controlled for potential global shocks (such as the financial crisis) that might have affected CO<sub>2</sub> emissions uniformly across countries. Country effects were treated as random, consistent with the assumption of no correlation between unobserved heterogeneity and explanatory variables. The model was validated by the characteristics of the fitted model: R<sup>2</sup> and adjusted R<sup>2</sup>; p-values of the Fisher and Student tests.

Finally, the data were statistically broken down into specific groups to identify regional trends. The results of the research are presented in the next section.

#### 4. EMPIRICAL RESULTS AND DISCUSSION

##### *Regression analysis*

Regression analysis was performed using a balanced data panel covering 28 countries over a 15-year period (420 observations). The dependent variable in the model is the CO<sub>2</sub> emissions per capita. The main explanatory variables include the gross domestic product (GDP) as a measure of economic development, the share of renewable energy consumption (renew), and the energy intensity (EN\_INTENSITY), which indicates energy efficiency. Two years of dummy variables (2009 and 2010) were included to eliminate the impact of the global financial crisis that occurred during those years. The main statistical parameters taken from the R package are presented in Table 2.

Table 2

The main statistical characteristics

Statistic	Value
Total Sum of Squares (TSS)	0.0071227
Residual Sum of Squares (RSS)	0.0030476
R-squared	0.57213
Adjusted R-squared	0.51865
F-statistic (df = 3, 24)	10.6974
Model p-value	0.00011796

*Source:* Authors' calculation using R software

The main characteristics of the regression analysis confirmed that the model is statistically significant ( $F = 10.70$ ,  $p < 0.001$ ).  $R^2$  was 0.572, which indicates that 57% of the variation in CO<sub>2</sub> emissions between countries was explained by the independent variables included. Values of coefficients and residuals are given below (Table 3).

Table 3

## Values of coefficients and residuals

Balanced panel: n = 28, T = 15, N = 420. Observations used in estimation: 28. Residuals range: -0.0213 to 0.0276. Significance levels: *** p < 0.001; ** p < 0.01; p < 0.05.					
Variable	Coefficient	Std. Error	t-value	p-value	Significance
Constant	-0.0435	0.0051	-8.5066	1.05e-08	***
GDP	0.5254	0.1194	4.3997	0.000191	***
Renewable energy	0.0640	0.0276	2.3146	0.0295	*
Energy intensity	0.0932	0.0794	1.1738	0.2520	
Residuals Summary					
Statistic			Value		
Minimum			-0.02134		
1st Quartile			-0.00454		
Median			-0.00070		
3rd Quartile			0.00441		
Maximum			0.02762		
Presented by R: <i>Source:</i> Authors' calculations					

*Source:* Authors' calculation using R software

Based on the results obtained, GDP has a positive effect on CO<sub>2</sub> emissions ( $\beta = 0.525$ ,  $p < 0.001$ ). The share of renewable energy consumption also has a positive effect on CO<sub>2</sub> emissions ( $\beta = 0.064$ ,  $p < 0.05$ ), although the magnitude of the effect is smaller. In contrast, the intensity of the energy does not have a statistically significant effect on CO<sub>2</sub> emissions ( $p > 0.25$ ). The coefficient of energy intensity ( $\beta = 0.093$ ) is positive, but this relationship is not statistically significant. These results reveal that richer countries tend to emit more CO<sub>2</sub> on average, which, according to the theory of ECG, should decrease at the specific turning point. The increase in the share of renewable energy consumption is associated with higher CO<sub>2</sub> emissions, which is a logical conclusion. Changes in energy intensity do not meaningfully explain changes in CO<sub>2</sub> emissions when GDP and renewable energy consumption are considered together.

#### Clustering of countries

The figure below (Fig. 2) shows the residual data for a further evaluation of the suitability of the model. The residual distribution is centered at zero (median  $\approx 0$ ), which is a good sign. The variance (approximately -0.021 to +0.028) indicates the range of prediction errors. The balance of negative and positive values reveals that there is no significant bias (the errors are approximately balanced). Most of the data points in the scatter plot are distributed around the 45-degree line, which indicates that the forecast is reasonably accurate.

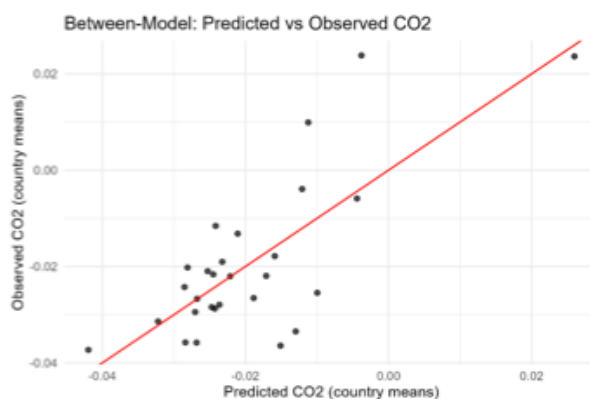
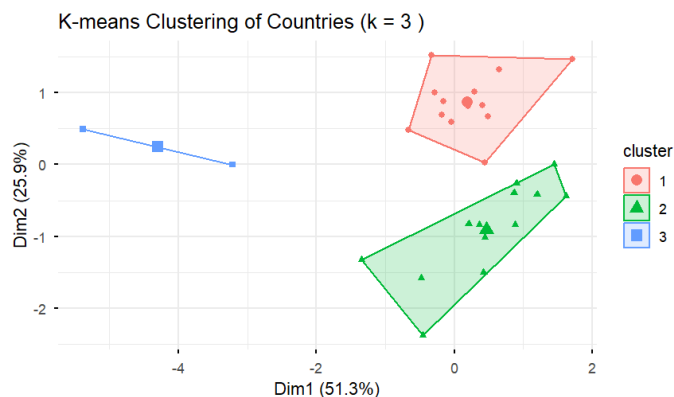


Figure 2. Comparison of Predicted and Observed CO<sub>2</sub> Values (Between-Model)

*Source:* compiled by the authors

The methods chosen to have shown that the proposed model explains the changes in CO<sub>2</sub> emissions in the selected sample. However, some deviations (Fig. 2) from the straight line indicate that there are other factors such as energy policy, implemented innovations, etc., which could explain these small discrepancies. The moderate fit reflects the structural heterogeneity between countries and the limited number of macroeconomic and policy variables included. Nevertheless, the model provides valuable information on long-term cross-country determinants of CO<sub>2</sub> emissions. The K-means clustering method was applied for craterisation. This method divides countries into groups based on their similarities between the variables chosen. The R package created three groups, as shown in the figure below (Fig. 3).



**Figure 3. K-means clustering - country clustering based on long-term averages**

*Source:* compiled by the authors

The first group consists of twelve countries (Belgium, Bulgaria, Cyprus, the Czech Republic, Denmark, Estonia, France, Germany, Greece, the Netherlands, Portugal, Romania and Spain, including all EU data). These countries show average CO<sub>2</sub> reductions, average GDP growth, average or high use of renewable energy, and average improvements in energy intensity. The group represents the average EU economy: stable GDP growth, adequate share of renewable energy, moderate CO<sub>2</sub> reduction, relatively efficient energy consumption (negative intensity).

The second group consists of thirteen countries: Austria, Croatia, Finland, Hungary, Italy, Latvia, Lithuania, Luxembourg, Poland, Portugal, Slovakia, Slovenia, and Sweden. This cluster represents average-performing EU economies that show stable but not particularly high progress across all indicators: CO<sub>2</sub>\_average is slightly negative (average reduction in emissions); positive but not particularly high GDP\_average – indicating stable economic growth; RENEW\_average – low or medium contribution of renewable energy, with a few higher cases (e.g., Luxembourg); EN\_INTENS\_average – slight improvement, or neutral – efficiency is improving, but not rapidly. These countries have balanced economies and are continuously improving their sustainability and the implementation of EU climate goals. These are mostly mid-sized or northern/central EU economies — not the biggest emitters (like Germany or France) nor the smallest or most atypical (like Malta or Ireland). So, structurally, it makes sense that they would fall into a balanced middle group.

The last group consists of two countries (Ireland and Malta). This cluster is small but cohesive, representing rapidly growing, small economies that differ significantly from the EU average: high GDP growth, renewable energy sources, and rapidly increasing efficiency (Malta's renewable energy sources are extreme outliers); and slightly increasing CO<sub>2</sub> emissions. This combination justifies their separation from the main EU clusters.

Although the explanatory power is moderate, the results are consistent with theoretical expectations: higher GDP and energy intensity are associated with higher emissions, whereas a greater share of renewable energy correlates with lower emissions. The model exploits the variation between countries (between) by averaging observations over time, thus identifying how differences in average GDP, renewable energy share, and energy intensity explain differences in average CO<sub>2</sub> emissions between countries. The network energy supply sector, performance is driven by a mix of primary energy sources – renewable and non-renewable, with renewable energy sources gaining prominence in recent years. In 2023, renewable energy made up ~44.7% of electricity generation in the EU, overtaking fossil fuels (32.5%) for the first time. This shift reflects the EU's strong commitment to decarbonizing its power sector. However, when looking at the overall energy mix (not just electricity), non-renewable sources still accounted for a substantial share — around 68–69% in 2023, according to Eurostat (Eurostat, 2024)). Regulatory, technological, geopolitical and socioeconomic factors are key forces influencing the development of the energy sector, while the performance and progress of the energy sector are evaluated through a set of climate and energy transformation indicators. It is important to track key indicators that monitor progress in reducing CO<sub>2</sub> emissions, including renewable energy consumption, installed renewable capacity, and CO<sub>2</sub> emissions, along with metrics that track the dynamics of climate warming and its associated impacts. The monitoring of these indicators is essential for assessing the effectiveness of the EU's climate change policies and their progress in meeting established climate objectives.

## 5. CONCLUSION

The model exploits the variation between countries (between) by averaging observations over time, thus identifying how differences in average GDP, renewable energy share, and energy intensity explain differences in average CO<sub>2</sub> emissions between countries. The regression analysis performed was statistically significant ( $R^2 = 0.572$ ;  $F = 10.70$ ,  $p < 0.001$ ). In the tested model, GDP positively affected CO<sub>2</sub> emissions ( $\beta = 0.525$ ,  $p < 0.001$ ). The share of the effect of renewable energy consumption on CO<sub>2</sub> emissions was also positive, but the impact is less compared to GDP ( $\beta = 0.064$ ,  $p < 0.05$ ). Indicators of energy intensity did not demonstrate a statistically significant effect on CO<sub>2</sub> emissions ( $p > 0.25$ ;  $\beta = 0.093$ ). This proves that increasing the consumption of renewable energy will result in a reduction in CO<sub>2</sub> emissions. However, further analysis is required to better understand the relationship between GDP and CO<sub>2</sub> emissions.

To reveal the development tendencies, the chosen sample was grouped (K-means clustering) into three groups according to the fluctuation of the chosen variables in line with studies by Hassan et al. (2024) and Chen et al. (2022). Two larger groups were fixed – the first group included 12 and the second 13 countries. The third group only captured two countries that demonstrated the specific variation of the chosen variables. Belgium, Bulgaria, Cyprus, the Czech Republic, Denmark, Estonia, France, Germany, Greece, the Netherlands, Portugal, Romania, and Spain, including all EU data, represent stable GDP growth, adequate share of renewable energy, moderate CO<sub>2</sub> reduction, relatively efficient energy consumption (negative intensity). Austria, Croatia, Finland, Hungary, Italy, Latvia, Lithuania, Luxembourg, Poland, Portugal, Slovakia, Slovenia, and Sweden show slightly negative CO<sub>2</sub> average emissions, stable economic growth, and low or medium contribution of renewable energy, with a few higher cases (e.g., Luxembourg) as well as efficiency is improving, but not rapidly. Ireland and Malta were clustered in the separate group as having high GDP growth, renewable energy sources, and rapidly increasing efficiency.

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