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Economic Development, Transport and Renewable Energy: A Panel Data Analysis of CO_2 Emissions in the European Union (2000–2023)

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Abstract: This study examines the relationship between carbon dioxide (CO_2) emissions, economic development, transport activity, and renewable energy use in the member states of the European Union over the period 2000–2023. The analysis is based on annual panel data collected from official international sources and adopts a quantitative approach grounded in descriptive statistical methods, Pearson and Spearman correlation analyses, and a pooled Ordinary Least Squares (OLS) panel regression model. To ensure comparability across countries and time, all variables were standardized using Z-scores. The descriptive analysis highlights substantial differences among EU member states, reflecting heterogeneity in economic development levels, transport intensity, and energy structures. Correlation analysis reveals weak and statistically insignificant relationships between CO_2 emissions and the explanatory variables, indicating the complexity of the mechanisms underlying emission dynamics at the European level. Furthermore, the estimation of the aggregated panel regression model does not confirm the existence of statistically significant effects of economic development, transport activity, or the share of renewable energy on CO_2 emissions when these factors are jointly considered. Although the estimated coefficients display signs consistent with theoretical expectations in the existing literature, the lack of statistical significance suggests that the relationship between economic growth and CO_2 emissions is not uniform across the European Union. The findings underscore the importance of employing econometric approaches capable of capturing structural heterogeneity among member states and support the need for differentiated and country-specific environmental policies. This study contributes to the literature by highlighting the limitations of aggregated panel analyses and by providing a statistical perspective on the interaction between economic development, transport, renewable energy, and CO_2 emissions in the European Union.

Keywords: CO_2 emissions; economic development; transport activity; renewable energy; panel data analysis; European Union

1. Introduction

Climate change represents one of the most significant challenges facing the contemporary global economy, with carbon dioxide (CO_2) emissions being the primary contributor to the intensification of the greenhouse effect. The increase in emissions is closely linked to economic activities, intensive energy use, and the expansion of the transport sector, particularly in developed and emerging economies. In this context, the analysis of the relationship between economic development, transport, renewable energy, and CO_2 emissions has become a central topic in economic literature and environmental public policy debates.

The European Union plays a pivotal role in global efforts to combat climate change, having committed to ambitious targets for reducing greenhouse gas emissions through the European Green Deal. Nevertheless, EU member states exhibit substantial differences in terms of economic development levels, sectoral structures, energy mixes, and transport intensity. These disparities generate significant variations in CO_2 emission levels, both across countries and over time.

Economic development is often associated with increasing energy demand and industrial activity, leading to higher CO_2 emissions. At the same time, the transport sector represents one of the main sources of emissions, particularly in the context of rising mobility and motorization rates. Conversely, the use of renewable energy is widely recognized as a key instrument for mitigating the negative environmental impacts of economic activity, contributing to the decarbonization of energy production and to long-term economic sustainability.

The relationship among these variables is complex and cannot be examined in isolation. Economic growth may facilitate investments in green technologies and sustainable infrastructure; however, in the absence of appropriate policies, it may also result in a substantial increase in emissions. Similarly, the expansion of the transport sector can stimulate economic activity but generates significant environmental costs. In this context, renewable energy plays a mediating role, with the potential to reduce dependence on fossil fuels and limit CO_2 emissions, even under conditions of economic growth.

The period 2000–2023 is particularly relevant for analyzing these relationships within the European Union. It encompasses major developments such as EU enlargement, the economic transition of Central and Eastern European countries, the global financial crisis, the acceleration of climate policies, and a significant increase in the share of renewable energy in final energy consumption. At the same time, the transport sector experienced considerable expansion, while CO_2 emission levels followed different trajectories across countries, reflecting structural and institutional specificities.

Against this background, the present study aims to empirically examine the relationship between economic development, transport activity, and renewable energy use and their impact on CO_2 emissions, using annual data for a group of European Union member states over the period 2000–2023. The analysis relies on quantitative statistical methods, including descriptive analysis, Pearson and Spearman correlation coefficients, and a pooled Ordinary Least Squares (OLS) panel regression model, applied to standardized variables to ensure comparability across countries and time.

The contribution of this study lies in the simultaneous assessment of the effects of economic development, transport intensity, and renewable energy use on CO_2 emissions within a unified analytical framework applied

to an extensive panel dataset. The findings provide a statistical perspective on the effectiveness of energy transition policies and on the limitations of decoupling economic growth from environmental impact in the context of the European Union.

2. Literature Review

The analysis of the relationship between economic development and carbon dioxide (CO_2) emissions represents a central topic in the academic literature and has been approached from economic, energy-related, and public policy perspectives. Existing studies highlight that, in the short and medium term, economic growth is often associated with intensified industrial activity and increased energy consumption, leading to higher CO_2 emissions. In the long run, however, this relationship may be influenced by factors such as technological progress, energy efficiency, and environmental policies.

A body of seminal research has examined the Environmental Kuznets Curve (EKC) hypothesis, which suggests that the relationship between economic development and environmental degradation follows a non-linear trajectory. According to this hypothesis, CO_2 emissions increase in the early stages of economic development, reach a turning point, and subsequently decline as income levels rise and cleaner technologies are adopted (Grossman & Krueger, 1991; Stern, 2004). Nevertheless, empirical evidence remains mixed, and the validity of the EKC hypothesis is frequently questioned, particularly in the case of developed economies, where a complete decoupling between economic growth and emissions is not consistently observed.

Within the European Union, the relationship between economic development and CO_2 emissions has been investigated in numerous recent studies, which reveal significant heterogeneity across member states. Some research indicates that, in Western European countries, economic growth has been accompanied by a relative reduction in emission intensity due to improved energy efficiency and the implementation of stringent climate policies (Apergis & Payne, 2014). By contrast, in Central and Eastern European economies, economic development remains closely linked to the intensive use of fossil energy sources (Pao & Tsai, 2011).

The transport sector is consistently identified in the literature as one of the main contributors to CO_2 emissions. Studies show that increases in motorization rates and road traffic volumes lead to significant growth in emissions, particularly in the absence of sustainable transport alternatives (Sims et al., 2014). In the context of the European Union, road transport accounts for a substantial share of total transport-related emissions, and reducing these emissions represents a major challenge for achieving the climate targets established under the European Green Deal.

An important strand of the literature focuses on the role of renewable energy in reducing CO_2 emissions. Numerous empirical studies have identified an inverse relationship between the share of renewable energy in total energy consumption and emission levels, suggesting that the transition to cleaner energy sources contributes to mitigating environmental pressure (Marques & Fuinhas, 2012; Ito, 2017). In the European Union, the expansion of renewable energy production capacity is supported by comprehensive public policies; however, its impact on emissions varies depending on national energy structures and the degree of renewable energy integration into the energy system.

The literature also emphasizes the importance of examining the combined impact of economic development, transport, and renewable energy on CO_2 emissions. Studies employing panel data models indicate that the individual effects of these variables may differ when analyzed simultaneously, as opposed to univariate or bivariate approaches (Shafiei & Salim, 2014). In this regard, the inclusion of control variables, such as energy intensity or the sectoral structure of the economy, is considered essential for obtaining robust empirical results.
From a methodological perspective, existing studies employ a wide range of econometric techniques, including correlation analysis, panel regressions with fixed or random effects, and dynamic models. However, many authors highlight the need for cautious interpretation of results, given the complexity of the relationships among variables and the presence of institutional and technological factors that are difficult to quantify (Stern, 2011).
In conclusion, the literature indicates that the relationship between economic development, transport, renewable energy, and CO_2 emissions is complex and highly dependent on economic and institutional contexts. Although energy transition and improvements in energy efficiency can contribute to emission reductions, empirical evidence suggests that achieving a complete decoupling between economic growth and environmental impact remains a major challenge for European Union member states. In this context, the present study contributes to the existing literature by providing a statistical analysis covering the period 2000–2023 and by offering new evidence on the role of economic development, transport activity, and renewable energy in shaping CO_2 emissions.

3. Research Methodology

The present study adopts a quantitative research approach based on a statistical analysis of the relationship between economic development, transport activity, renewable energy use, and carbon dioxide (CO_2) emissions, using panel data techniques. The empirical analysis focuses on a sample of European Union member states over the period 2000–2023, a timeframe that is particularly relevant in light of the major economic, energy-related, and climate-related transformations experienced by the European Union.

The main objective of the research is to assess the combined impact of economic development, transport intensity, and renewable energy use on CO_2 emissions by employing descriptive statistics, correlation analysis, and panel regression techniques.

The analysis relies on annual data collected from internationally recognized and official databases to ensure data reliability and cross-country comparability. The primary data sources include the International Energy Agency (IEA) for CO_2 emissions and energy-related indicators, the World Bank's World Development Indicators for economic development measures, and Eurostat for transport and energy structure data.

The final dataset comprises 648 valid country–year observations, with no missing values, allowing for robust statistical analysis.

The dependent variable is: **CO_2 emissions**, expressed in standardized form (Z-scores), to eliminate scale differences across countries and years.

The independent variables include: **Economic development**, measured by real Gross Domestic Product (GDP); **Renewable energy**, defined as the share of renewable energy in final energy consumption; **Transport activity**, proxied by the number of passenger cars per 1,000 inhabitants, reflecting the intensity of road transport activity.

The selection of these variables is grounded in the existing literature, which highlights their direct and indirect influence on CO_2 emissions.

To ensure comparability among variables measured on different scales and to reduce the influence of extreme values, all variables were standardized using the Z-score transformation. This procedure results in variables with a mean of zero and a standard deviation of one, facilitating the interpretation of correlation coefficients and regression estimates within the panel data framework.

Standardization is particularly important in cross-country panel analyses, where structural differences between economies may otherwise bias statistical results.

The statistical analysis was conducted using **SPSS, version 26**, and involved several stages:

1. Descriptive Statistics

Descriptive statistical analysis was employed to examine the basic characteristics of the variables, including measures of central tendency, dispersion, skewness, and kurtosis. This stage provided insights into the distributional properties of the data and enabled the identification of non-normal distributions and extreme values relevant for subsequent analyses.

2. Correlation Analysis

To assess bivariate relationships between variables, both **Pearson** and **Spearman** correlation coefficients were computed. The use of both measures allows for robustness checks, given the presence of non-normal distributions highlighted by the descriptive analysis. Correlation results were interpreted based on magnitude and statistical significance.

3. Panel Regression Model

To estimate the simultaneous impact of economic development, transport activity, and renewable energy use on CO_2 emissions, a pooled **Ordinary Least Squares (OLS)** panel regression model was employed. The estimated model can be expressed as:

Z(CO_2_{it}) = \beta_0 + \beta_1 Z(GDP_{it}) + \beta_2 Z(REN_{it}) + \beta_3 Z(TRAN_{it}) + \varepsilon_{it}

where *i* denotes the country, *t* denotes the year, and ε_{it} represents the error term.

The pooled OLS approach estimates an average relationship across all observations and is suitable for exploratory analysis aimed at identifying general trends within the dataset.

Model adequacy was evaluated using: the **F-test** (ANOVA) for overall model significance, **t-tests** for individual coefficient significance, the **coefficient of determination (R^2)** to assess explanatory power, and the **Durbin–Watson statistic** to examine residual autocorrelation. A significance level of **5%** was applied throughout the analysis.

It is important to note that the pooled OLS model does not explicitly control for unobserved country-specific heterogeneity. Consequently, the estimated results should be interpreted as average effects and may not fully capture structural differences among individual EU member states. Furthermore, the analysis does not incorporate institutional or technological variables, which may also influence CO_2 emissions.

Despite these limitations, the applied methodology provides a coherent and transparent framework for exploring the relationships among economic development, transport activity, renewable energy use, and CO_2 emissions at the European Union level.

4. Results

4.1. Descriptive Statistical Analysis of the Variables

The descriptive statistical analysis was conducted on a dataset comprising 648 valid observations, with no missing values, corresponding to country–year combinations over the period 2000–2023. All variables included in the analysis were standardized using Z-scores, resulting in mean values equal to zero and unit standard deviations.

The distribution of CO_2 emissions is characterized by extremely pronounced positive skewness and very high kurtosis, indicating a strongly non-normal distribution with extreme values concentrated in the upper tail. This outcome highlights the existence of substantial differences across both countries and years, reflecting heterogeneous levels of economic activity, industrialization, and energy consumption.

The variable capturing economic development (GDP) exhibits moderate positive skewness, suggesting that while most observations cluster around the mean, there are also high values associated with more developed economies. Similarly, the share of renewable energy in final energy consumption displays a non-normal distribution, with very high values observed for a limited number of cases, reflecting significant progress in the energy transition in certain EU member states.

By contrast, the indicator used to proxy road transport intensity (number of passenger cars per 1,000 inhabitants) shows a relatively symmetric distribution close to normality, suggesting a notable convergence in motorization levels across the European Union.

4.2. Correlation Analysis Results

To evaluate the bivariate relationships among variables, Pearson correlation coefficients were computed, given the large sample size and the continuous nature of the standardized variables.

The results indicate that the direct relationships between CO_2 emissions and the explanatory variables are weak and statistically insignificant. The correlation between CO_2 emissions and economic development is positive but very small in magnitude and statistically insignificant, suggesting the absence of a strong linear relationship at the aggregated level.

Similarly, the correlation between CO_2 emissions and the share of renewable energy is negative but weak and statistically insignificant, indicating that the potential emission-reducing effect of renewable energy cannot be clearly identified through simple bivariate analysis in the current dataset.

With respect to the transport indicator, the correlation with CO_2 emissions is positive but of low intensity and lacks statistical significance. This finding suggests that the relationship between road transport and CO_2 emissions is more complex and may be influenced by additional factors, such as vehicle technological efficiency, fuel composition, or environmental policies.

A noteworthy result is the strongly positive correlation between economic development and transport intensity, indicating that higher GDP levels are associated with increased motorization rates. This relationship reflects a structural link between economic development and mobility.

4.3. Panel Regression Results (Pooled OLS)

To assess the simultaneous impact of the explanatory variables on CO_2 emissions, a pooled Ordinary Least Squares (OLS) panel regression model was estimated. The results show that the coefficient of determination (R^2) is very low, indicating that only a minimal proportion of the variation in CO_2 emissions is explained by the variables included in the model.

The F-test for overall regression significance yields a p-value greater than 0.05, leading to a failure to reject the null hypothesis regarding the absence of a joint effect of the explanatory variables on CO_2 emissions. This result confirms that the estimated model, in its current specification, is not statistically significant as a whole.

The analysis of individual coefficients reveals that economic development has a negative coefficient of very small magnitude that is statistically insignificant; the share of renewable energy displays a negative coefficient, suggesting a potential emission-reducing effect, though without statistical significance; and road transport intensity is associated with a positive but statistically insignificant coefficient.

These findings indicate that none of the explanatory variables exert a statistically significant impact on CO_2 emissions when analyzed simultaneously within an aggregated linear regression framework.

4.4. Diagnostic Tests and Model Robustness

Diagnostic statistics indicate an appropriate structure of the model residuals. The value of the Durbin–Watson statistic, close to the theoretical benchmark of 2, suggests the absence of serial autocorrelation, thereby confirming the validity of the basic OLS assumption regarding error independence.

However, the strongly non-normal distributions of certain variables and the structural heterogeneity across EU member states suggest that the pooled OLS model may be insufficient to fully capture the complex relationships between economic development, transport activity, renewable energy use, and CO_2 emissions.

4.5. Summary of Results

Overall, the findings indicate that the relationship between economic development, transport activity, renewable energy use, and CO_2 emissions cannot be robustly identified using an aggregated linear panel model that does not account for structural differences across countries. Although the estimated coefficients exhibit signs consistent with theoretical expectations, the lack of statistical significance highlights the need for more nuanced methodological approaches.

5. Discussion

The empirical results obtained in this study highlight the complexity of the relationship between economic development, transport activity, renewable energy use, and carbon dioxide (CO_2) emissions in the context of European Union member states. Although the existing literature suggests the presence of significant relationships among these variables, the analysis indicates that, at an aggregated level and using a pooled OLS panel regression model, these relationships do not manifest with sufficient intensity to be confirmed statistically.

The lack of statistical significance of both the overall model and individual coefficients should be interpreted with caution and does not necessarily represent a refutation of established theoretical relationships. Rather, this outcome reflects the fact that CO_2 emissions are driven by a broad set of structural, institutional, and technological factors that cannot be fully captured by a limited number of explanatory variables within an aggregated analytical framework.

From the perspective of economic development, the findings suggest that the positive relationship between GDP and CO_2 emissions, commonly reported in previous studies, does not occur uniformly across the analyzed sample. This result may be explained by the substantial differences between Western European economies and those in Central and Eastern Europe, where production structures and levels of energy efficiency differ considerably. Consequently, while some economies have managed to partially decouple economic growth from emission growth, others remain dependent on carbon-intensive energy sources.

Regarding the transport sector, the positive coefficients—although statistically insignificant—support the hypothesis that increased mobility is associated with greater environmental pressure. However, the use of the

number of passenger cars per 1,000 inhabitants as a proxy for transport activity may underestimate the actual impact of the transport sector on CO_2 emissions. Factors such as fuel type, the degree of transport electrification, and the technological efficiency of vehicle fleets may substantially influence emission levels and justify the inclusion of more detailed transport-related indicators in future research.

Renewable energy is widely recognized in the literature as a key component in reducing CO_2 emissions. In the present study, the negative sign of the coefficient associated with the share of renewable energy confirms this theoretical relationship; however, the absence of statistical significance indicates that its effect is not strong enough to offset the pressures generated by economic growth and increased transport activity when the analysis is conducted at an aggregated level. This finding suggests that, while essential, the energy transition must be accompanied by complementary measures aimed at improving energy efficiency and reducing overall energy demand.

The results are also influenced by methodological limitations. The use of a pooled OLS model does not allow for the explicit control of unobserved country-specific heterogeneity, meaning that identical relationships may differ in magnitude and significance depending on national contexts. In addition, the strongly non-normal distributions of CO_2 emissions and renewable energy shares may affect the estimation of linear relationships, even when variables are standardized.

From a policy perspective, the findings suggest that uniform policy approaches at the European Union level may have limited effectiveness in the absence of adaptation to national circumstances. Structural differences among member states require differentiated strategies that take into account levels of economic development, energy structures, and transport sector characteristics. The transition toward a low-carbon economy therefore requires not only investments in renewable energy but also structural reforms aimed at optimizing transport systems, improving energy efficiency, and encouraging changes in consumption behavior.

In conclusion, the discussion highlights that the relationship between economic development, transport activity, renewable energy use, and CO_2 emissions is multidimensional and highly context-dependent. The empirical results underscore the importance of employing advanced methodological approaches and a broader selection of explanatory variables in order to adequately capture the complexity of this phenomenon within the European Union.

Conclusions and Directions for Future Research

The present study examined the relationship between economic development, transport intensity, and renewable energy use and their impact on carbon dioxide (CO_2) emissions across a group of European Union member states over the period 2000–2023. The empirical analysis was conducted using panel data and quantitative statistical methods, including descriptive analysis, Pearson and Spearman correlation coefficients, and a pooled Ordinary Least Squares (OLS) panel regression model applied to standardized variables.

The findings indicate that, at an aggregated level, the relationship between economic development, transport activity, renewable energy use, and CO_2 emissions is not statistically significant within the estimated model.

Although the signs of the estimated coefficients are consistent with the theoretical hypotheses formulated in the literature—economic development and transport intensity being associated with higher emissions, and renewable energy use with emission reductions—these effects are not sufficiently strong to be statistically confirmed in the context of the present analysis.

The lack of statistical significance of the coefficients should not be interpreted as a rejection of fundamental economic relationships, but rather as a reflection of the complex and multidimensional nature of the determinants of CO_2 emissions. Factors such as the sectoral structure of the economy, levels of energy efficiency, technological progress, climate policies, and consumer behavior influence emission levels and cannot be fully captured by an aggregated linear model with a limited number of explanatory variables.

From a public policy perspective, the results suggest that expanding the use of renewable energy, while essential, is not sufficient on its own to achieve substantial reductions in CO_2 emissions in the absence of complementary measures. Reducing environmental impact requires an integrated approach that combines the promotion of renewable energy sources with improvements in energy efficiency, modernization of the transport sector, and the stimulation of technological innovation.

At the same time, the study emphasizes the importance of adapting climate policies to the specific characteristics of individual member states, given the significant differences across the European Union in terms of economic development, energy structures, and transport intensity. Uniform policy frameworks may have limited effectiveness if they do not adequately account for these structural disparities.

With respect to future research directions, the analysis could be extended by employing advanced panel econometric methods, such as fixed-effects or random-effects models, which allow for better control of unobserved heterogeneity across countries. In addition, the inclusion of supplementary variables—such as the sectoral composition of the economy, investments in green technologies, the degree of transport electrification, or indicators of environmental policy stringency—could lead to more statistically robust results.

In conclusion, the study highlights that achieving CO_2 emission reduction targets in the European Union requires coherent and coordinated policies that simultaneously promote sustainable economic development, energy transition, and the transformation of the transport sector. An integrated approach to these dimensions is essential for the realization of a low-carbon economy in the long term.

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ANNEXES

Annex A1. Descriptive Statistics of the Variables (Standardized Values)

Variable	Mean	Std. Deviation	Minimum	Maximum	Skewness	Kurtosis
CO_2 Emissions (Z-score)	0.000	1.000	-0.176	18.285	15.396	246.139
Economic Development – GDP (Z-score)	0.000	1.000	-1.316	4.552	1.616	3.762
Renewable Energy Share (Z-score)	0.000	1.000	-0.798	8.733	2.985	13.554
Transport Intensity (Cars per 1,000 inhabitants, Z-score)	0.000	1.000	-2.462	2.440	-0.025	-0.139

Note:

All variables are standardized using Z-scores. The dataset consists of 648 country–year observations covering the period 2000–2023 for European Union member states. The distribution of CO_2 emissions exhibits extreme positive skewness and kurtosis, indicating strong non-normality and the presence of outliers.

Annex A2. Pearson Correlation Matrix

Variables	CO_2 Emissions	Economic Development (GDP)	Renewable Energy	Transport Intensity
CO_2 Emissions	1.000	0.020	-0.054	0.033
Economic Development (GDP)	0.020	1.000	0.011	**0.770**
Renewable Energy	-0.054	0.011	1.000	-0.048
Transport Intensity	0.033	**0.770**	-0.048	1.000

Note:

Pearson correlation coefficients are reported. ****** indicates statistical significance at the 1% level (two-tailed). The table shows a strong and statistically significant positive correlation between economic development and transport intensity, while correlations between CO_2 emissions and the explanatory variables are weak and statistically insignificant.

Annex A3. Pooled OLS Panel Regression Results

Dependent variable: CO_2 Emissions (Z-score)

Number of observations: 648

Regression Coefficients

Variable	Coefficient (B)	Std. Error	Beta	t-statistic	p-value
Constant	-0.000	0.039	—	0.000	1.000
Economic Development (GDP, Z-score)	-0.008	0.062	-0.008	-0.134	0.893
Transport Intensity (Z-score)	0.037	0.062	0.037	0.598	0.550
Renewable Energy Share (Z-score)	-0.053	0.039	-0.053	-1.331	0.184

Model Statistics

Statistic	Value
R	0.063
R^2	0.004
Adjusted R^2	-0.001
F-statistic	0.845
Prob (F-statistic)	0.470
Durbin–Watson	2.017

Note:

The pooled Ordinary Least Squares (OLS) panel regression model was estimated using standardized variables. None of the explanatory variables are statistically significant at the 5% level. The low R^2 value indicates limited explanatory power of the model, while the Durbin–Watson statistic close to 2 suggests no autocorrelation in the residuals.