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# The Relationship Between Renewable Energy Consumption, Carbon Dioxide Emissions, Economic Growth, and Foreign Direct Investment: Evidence from Developed European Countries

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**ABSTRACT**

The objective of this study is to conduct an empirical examination of how renewable energy consumption, carbon dioxide emissions, growth in GDP per capita, and foreign direct investment are interrelated. The empirical investigation is based on panel data spanning 18 years, gathered from nine developed European nations: Germany, the United Kingdom, France, Italy, Spain, the Netherlands Switzerland, Turkey, and Poland, during the period from 2002 through 2019, encompasses significant macroeconomic factors that act as benchmarks for assessing a socioeconomic advancement. Additionally, in light of the drawbacks posed by Carbon dioxide ($CO_2$) emissions, which are a significant hazard to all countries, there appears to be a growing potential for developing preventive measures. Regarding the methodology, various models are examined using panel regression econometric methods. This study utilizes Pooled Ordinary Least Squares (OLS), Pooled Ordinary Least Squares Robust (OLSR), Fixed Effects Method (FEM), and Random Effects Method (REM). A correlation matrix is used to ascertain the interrelationships among the variables under study. Additionally, the findings from the Hausman Test suggest that the Random Effects Method emerges as the most fitting technique for this investigation. Moreover, the regression outcomes obtained through the random effect approach indicate that renewable energy consumption notably decreases $CO_2$ emissions in developed European nations, highlighting its critical role as a strategy for sustainability. While GDP per capita has a negative impact on $CO_2$ emissions and does not indicate a level of significance. Further, Foreign Direct Investment has a positive impact on $CO_2$ emissions although, does not indicate a level of significance. This paper's major goal is to advance our knowledge of this relationship and arrive at fresh insights that could be very useful to policymakers. The study's secondary goal is to bridge the existing literature gap for the specified period and selected countries, with a focus on distinct macroeconomic variables.

## 1. INTRODUCTION

Energy holds a pivotal role as a fundamental cornerstone in the development of contemporary society, playing an essential part in virtually every aspect of modern life. It powers homes, fuels transportation systems, drives industrial processes, and is integral to technological advancements and innovations. Beyond these functional uses, energy is also deeply intertwined with the quality of life, influencing everything from healthcare and education to communication and leisure activities.

Moreover, energy's significance extends to its impact on economic development. It's a key driver of economic growth, enabling businesses to operate efficiently and competitively in the global market. Access to reliable and affordable energy sources can lead to increased productivity, job creation, and improved standards of living. However, energy's role in human survival goes beyond mere economic and functional aspects. It's crucial for basic human needs, like heating, cooking, and access to clean water. In many parts of the world, energy poverty remains a critical barrier to social and economic progress, with a significant portion of the global population lacking access to electricity and clean cooking facilities. Furthermore, the type of energy used and its sources have profound implications for the environment. The reliance on fossil fuels, for instance, has led to significant environmental challenges, including air pollution and climate change. This has prompted a global shift towards renewable energy sources, which are seen as more sustainable and less harmful to the planet. The transition to renewables is not just an environmental imperative but also a necessity for the long-term sustainability of human societies. In summary, energy is not just a utility or a commodity; it's a fundamental element that underpins the advancement and survival of modern society. Its role encompasses a broad spectrum, from driving economic growth and development to meeting basic human needs and addressing environmental challenges. A reliable supply of energy is essential for economic development. An economy's ultimate goal is to reach the desired level of sustainable economic growth. The demand for energy in human society has surged dramatically, primarily due to two key factors: the rapid growth of the global population and the expansive development of the world economy. This increased need for energy has led to several critical issues, particularly in the realms of environmental contamination and ecosystem damage. Firstly, the burgeoning population has heightened the need for energy in everyday life, industry, and transportation. As more people inhabit the planet, the demand for energy for residential purposes, such as heating, cooling, and lighting, as well as for commercial and industrial activities, escalates. This rising energy demand is a direct consequence of not just the increasing number of people but also the growing aspirations and evolving lifestyles that demand higher energy consumption. Secondly, the development of the global economy plays a significant role in energy consumption. As economies grow and industrialize, their energy needs escalate. This is particularly evident in emerging economies where rapid industrial growth, urbanization, and increasing wealth lead to higher energy consumption per capita. The expansion of the manufacturing sector, the proliferation of electronic devices, and the growing transportation network all contribute to this rise in energy demand. However, this escalating demand for energy brings with it significant environmental challenges. The use of fossil fuels, such as coal, oil, and natural gas, which currently dominate the global energy supply, is a major contributor to environmental issues. The combustion of these fuels releases a large amount of carbon dioxide ($CO_2$) and other greenhouse gases, which are primary drivers of global climate change. Additionally, the extraction and burning of fossil fuels result in air and water pollution, harming both human health and the natural environment. The environmental impact of fossil fuel usage extends to ecosystem damage. Habitats are disrupted by mining and drilling activities, and air and water pollution from fossil fuels can have devastating effects on local flora and fauna. Acid rain, caused by emissions from fossil fuel combustion, can damage forests and aquatic ecosystems, further exacerbating environmental degradation. The increasing need for energy driven by population growth and economic development poses significant environmental challenges. The reliance on fossil fuels for energy exacerbates issues like climate change, pollution, and ecosystem damage, underscoring the urgent need for a transition to more sustainable and environmentally friendly energy sources.

As a result of the waste materials created by burning fossil fuels, nitrides, sulfides, and soot will accumulate in the air; additionally, the rise in greenhouse gas emissions, including those of carbon dioxide ($CO_2$), nitrous oxide ($N_2O$), freon, methane ($CH_4$), and others, will result in global warming, raise sea levels, melting glaciers, and increase the frequency of extreme weather events, seriously endangering human production and life [1]. The increasing focus on renewable energy in the context of a sustainable energy future necessitates a deeper understanding of the intricate relationship between renewable energy consumption and economic growth. This connection is multi-faceted and has significant implications for policy, environmental sustainability, and the long-term health of economies worldwide.

**Policy Implications**: As governments and international organizations strive to meet climate goals and reduce carbon footprints, renewable energy emerges as a key policy tool. Understanding how renewable energy consumption impacts economic growth can guide policy decisions related to energy infrastructure, investment in renewable technologies, and the transition from fossil fuel-based energy systems. Policies need to balance the promotion of renewable energy with the economic needs of a country, ensuring that this transition supports sustainable economic development.

**Environmental Sustainability**: The shift to renewable energy is driven by the need to address environmental challenges such as climate change and pollution. By comprehending the dynamics between renewable energy use and economic growth, stakeholders can better understand how this transition might affect environmental outcomes. A positive relationship suggests that increasing renewable energy consumption can spur economic growth while also achieving environmental objectives.

**Economic Growth and Development**: The economic impacts of transitioning to renewable energy are profound. In regions where renewable energy sources are abundant, there can be a boost in economic activities, job creation in new sectors, and an overall increase in the gross domestic product. However, this transition also poses challenges, particularly in regions heavily reliant on traditional energy sectors, necessitating strategies to mitigate any negative economic impacts.

**Technological Innovation and Investment**: The relationship between renewable energy and economic growth is closely tied to technological innovation. As demand for renewable energy increases, it drives investment in research and development, leading to more efficient and cost-effective renewable technologies. This, in turn, can fuel economic growth, creating a positive feedback loop.

**Global and Local Contexts**: The impact of renewable energy on economic growth can vary significantly between developed and developing countries. In developed countries, the transition might be smoother due to existing infrastructure and technological capabilities. In contrast, developing countries might face more significant challenges due to limited resources, but they also have the potential for rapid growth by leapfrogging to advanced renewable technologies.

Comprehending the relationship between renewable energy consumption and economic growth is vital in navigating the transition to a sustainable energy future. It involves considering environmental benefits, economic implications, technological advancements, and the specific needs of different regions, all of which are critical for making informed decisions in energy policy and planning.

It should be highlighted that while the connection between energy consumption and economic growth has been thoroughly investigated in academic literature [2], the focus on renewable energy consumption in studies is a relatively newer area of exploration. Developed, industrialized countries are often better equipped in terms of institutional capacity and available resources compared to their less developed counterparts. This advantage plays a crucial role in their ability to formulate and implement strategies aimed at reducing reliance on nonrenewable energy sources and promoting the use of renewable energy. The expansion on this topic can be viewed from several perspectives. Developed countries typically have more financial and technological resources, which enable them to invest in renewable energy infrastructure and research. This investment is crucial for developing new technologies, improving existing ones, and reducing the costs associated with renewable energy. The ability to allocate resources effectively allows these countries to implement comprehensive energy policies that support a transition toward renewable energy. Stronger institutional frameworks in developed nations facilitate the development and enforcement of regulations and incentives that promote renewable energy. These frameworks include legal systems, regulatory bodies, and policy-making institutions that can efficiently design, monitor, and revise energy policies as needed. Developed countries often have more diversified and stable economies, which can better absorb the initial costs and potential economic disruptions associated with transitioning to renewable energy. This stability allows for long-term planning and investment in sustainable energy solutions. Despite these advantages, the practicality and effectiveness of renewable energy policies can vary significantly from one country to another. Factors such as geographic location, availability of natural resources (like sunlight, wind, and water), cultural attitudes toward energy consumption, and the existing energy infrastructure can influence how successful these policies are in different countries. In contrast, less developed countries may face more significant challenges in transitioning to renewable energy. These challenges include limited financial resources, lack of technological expertise, and weaker institutional structures. However, these countries also have opportunities to leapfrog to advanced renewable technologies, bypassing some of the stages that developed countries had to go through. The disparity in capabilities between developed and developing countries underscores the importance of international collaboration. Developed countries can play a crucial role in supporting less developed nations through technology transfer, financial assistance, and capacity-building initiatives. In summary, the capacity of developed countries to shift towards renewable energy sources is significantly influenced by their institutional and resource strengths. However, the varying characteristics of each nation mean that the practicality and success of renewable energy policies are not uniform. Addressing these disparities and fostering international cooperation is essential for a global transition to sustainable energy.

This paper is organized into five sections namely, Section 2 provides reviews of the literature; Section 3 contains the research methodology and data of the panel evidence; Section 4 provides the results generated and discussion arising from the relevant topic, and Section 5 provides the findings and conclusion given by the authors. Additionally, the main argument for this study is that only a few studies have examined the relationship between macroeconomic variables such as renewable energy consumption, carbon dioxide emissions, economic growth, and foreign direct investment, for this period, the sample of countries and these econometric models were applied. Consequently, there is a gap in the literature that this study aims to fill.

## 2. LITERATURE REVIEW

Since the global renewable energy industry is expanding quickly and there is a rising focus on the energy transition globally, the academic community has begun to place importance on the role of renewable energy in economic growth [3]. Nonetheless, research has divided the usage of renewable and non-renewable energy [1, 4]. Numerous studies have examined the relationship between the use of renewable energy and economic growth; some of these studies stress that increasing the use of renewable energy will stimulate economic growth [5].

The usage of renewable energy or its contribution to the total energy mix has a positive and statistically significant impact on economic growth, according to an evaluation of the relationship between renewable energy consumption and economic welfare. Ivanovski et al. [6] utilized a non-parametric modeling method to investigate the varying effects of renewable and non-renewable energy use on economic growth over time. While, consumption of both renewable and non-renewable energy contributes to economic growth in non-OECD countries, indicating that despite technical limitations, developing countries may be crucial in the shift to renewable energy. Bhattacharya et al. [7] examined that renewable energy consumption has a significant positive impact on the economic output of 57% of the countries included in the sample. Apergis and Payne [8] investigated the association between the use of renewable energy and economic development for a panel of 20 OECD countries from 1985 to 2005, results show that consumption of renewable energy and economic growth are causally related in both the short- and long-term. Chica-Olmo et al. [9] in their study which covers 26 European countries found that changes in renewable energy (REC) have an impact on neighboring countries' GDP, emphasizing that a 1% increase in a country's use of renewable energy (REC) will result in an increase in GDP of up to 0.054% for its neighboring nations. Wang and Wang [10] found that the effect of renewable energy consumption (REC) on economic growth is positive, which suggests that increased renewable energy promotes economic growth. Further, Germany's economic growth has increased by 0.2194% for every 1% rise in renewable energy use [11].

Li and Leung [12] revisited the renewable energy (RE) and economic growth (EG) in seven European countries for the 34-year period namely, 1985–2018 and findings offer empirical proof of the pivotal significance of economic growth and non-renewable energy pricing in the renewable energy transitions. Bozkurt and Yusuf [13] examined the impact of economic growth (EG), $CO_2$ emissions, and energy consumption in Turkey. Moreover, findings indicate that $CO_2$ emissions have a negative impact on economic growth (EG) while energy consumption (EC) impact positively the economic growth (EG) during the period 1960-2010. He et al. [14] highlighted the unidirectional Granger causal relationships between GDP, energy use, and FDI in the sampled countries. Kaplan et al. [15] investigate how rising energy consumption (EC) directly impacts both economic growth (EG) and increased energy consumption (EC).

Moreover, some other research in this field examines a negative relationship between the consumption of renewable energy and economic growth, an argument which is justified by the increased price of energy and the increased price affects the economic decline [16]. Further, the same impact is also presented in the literature by authors such as Ocal and Aslan [17]. Additionally, some other authors through their research articles express that renewable energy consumption does not have a significant impact on economic growth [18].

The European Union (EU) member states have exhibited diverse trajectories in augmenting the share of renewable energy within their total final energy consumption. This variation is especially pronounced in their pursuit of meeting the objectives set by EU directives. Notably, several nations, including Sweden, Finland, Denmark, and Estonia, have not only met but exceeded their renewable energy targets. In contrast, countries such as France, Germany, Spain, and the Netherlands are still in the process of reaching these goals.

The differences in progress among these countries can be attributed to several factors, particularly in sectors like transportation and heating. Key among these factors is the disparity in the existing stocks of equipment across these countries. The types and ages of machinery and appliances currently in use can significantly influence the ease with which renewable energy technologies can be integrated and utilized effectively.

Moreover, the infrastructure available in each country plays a crucial role. Infrastructure, in this context, encompasses the physical components necessary for the distribution and utilization of renewable energy, such as power grids, charging stations for electric vehicles, and facilities for renewable heating. The state of this infrastructure can vary widely between countries, impacting the speed and efficiency of transitioning to renewable energy sources.

Another critical factor is the diffusion of technology. This involves the adoption rate and spread of new renewable energy technologies among the populace and industries of different countries. Technological diffusion is influenced by various elements, including government policies, public awareness, economic incentives, and the availability of technical expertise. Countries that are more proactive in promoting and investing in new renewable energy technologies tend to progress faster in increasing their renewable energy share.

In summary, while the majority of EU nations are committed to increasing the use of renewable energy, their paths toward achieving this goal differ significantly. These differences are largely due to variations in equipment stocks, the state of infrastructure, and the rate of technology diffusion in the transportation and heating sectors.

## 3. DATA AND RESEARCH METHODOLOGY

This research employs secondary data to perform an empirical analysis, focusing on a panel dataset that encompasses nine developed European countries: Germany, the United Kingdom, France, Italy, Spain, the Netherlands, Switzerland, Turkey, and Poland. The data for these nations were sourced from the World Bank Database, spanning a significant time frame of 18 years, from 2002 to 2019. The selection of these specific countries for the study was intentional, aiming to assess the influence of various pertinent variables within the context of developed nations, particularly during this defined period. This timeframe and the choice of countries provide a comprehensive view of the trends and patterns in developed European economies, offering valuable insights into the impact of different economic and policy variables over nearly two decades. In this study, the analysis of the data was conducted using a suite of econometric methods, specifically Ordinary Least Squares (OLS), OLS with Robust standard errors, Fixed Effects, and Random Effects models. These methodologies were chosen for their robustness and suitability in analyzing panel data, particularly in the context of economic research. The statistical analysis was carried out using the STATA software, a widely recognized tool in the field of econometrics for its efficiency and accuracy in handling complex data sets.

The variables incorporated in this analysis are critical indicators of economic and environmental performance. These include $CO_2$ emissions (CO), which serve as a primary measure of environmental impact; GDP per capita growth (GDPC), an indicator of economic development; renewable energy consumption (REC), highlighting the shift towards sustainable energy sources; and foreign direct investment (FDI), reflecting the level of international economic integration and investment.

The primary objective of the study is to explore and understand the interrelationships among these selected variables in the context of the nine developed European countries. By focusing on this specific set of countries and variables, the study aims to provide a targeted and nuanced understanding of how economic growth, environmental factors, and international investment interact in developed economies. This approach ensures that the findings are relevant and tailored to the specific economic and environmental dynamics of these countries, offering valuable insights for policymakers, researchers, and stakeholders interested in the economic and ecological trajectories of developed European nations.

### 3.1 The specification of the model

In the study, a general standard model is employed as the foundational framework for the analysis. This model is structured in a specific format to systematically examine the relationships between the chosen variables. The form of the model is carefully designed to capture the dynamics and interactions among the key indicators, such as $CO_2$ emissions, GDP per capita growth, renewable energy consumption, and foreign direct investment.

The model's construction is based on established econometric principles, ensuring that it accurately reflects the complexities and nuances of the economic and environmental variables under study. By using a general standard model, the analysis benefits from a structured and methodical approach, allowing for clear interpretation and robust results. This model serves as the backbone of the analysis, guiding the empirical investigation and enabling a thorough exploration of the interplay among the selected variables in the context of the nine developed European countries. Overall, the use of a general standard model in this study ensures that the analysis is grounded in a solid theoretical and methodological framework, providing a reliable basis for understanding the intricate relationships among economic growth, environmental impact, renewable energy adoption, and foreign investment in these developed countries:

$$Yit = \beta_o + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \mu i \quad (1)$$

In the specified model, the focus is on examining the influence of various independent variables on a specific dependent variable over time and across different countries. Here, *Yit* represents the dependent variable, which in this study is carbon dioxide emissions ($CO_2$) for country *i* at time *t*. This choice of dependent variable underscores the study's emphasis on environmental impacts, particularly those related to climate change.

The independent variables, denoted by *X*, are a vector of control variables that include GDP per capita, renewable energy consumption, and foreign direct investment. These variables have been chosen for their potential influence on sustainable economic growth, reflecting key aspects of economic development, energy policy, and international economic engagement.

In the model, $\beta 1$, $\beta 2$, and $\beta 3$ represent the coefficients of the independent variables $X1$, $X2$, and $X3$, respectively. These coefficients are of primary interest as they quantify the effect of each independent variable on the dependent variable, $CO_2$ emissions. For example, $\beta 1$ captures the impact of GDP per capita on $CO_2$ emissions, allowing for an assessment of how economic growth correlates with environmental impact.

The term $\mu i$ in the model accounts for the unobserved effects that are unique to each country but constant over time, capturing latent factors that might influence $CO_2$ emissions beyond the included independent variables.

The goal of the analysis is to estimate these coefficients, particularly $\beta 1$, to understand the effect of each control variable (X) on the dependent variable (Y). This estimation will provide insights into how GDP per capita, renewable energy consumption, and foreign direct investment are associated with $CO_2$ emissions in the context of the selected developed European countries. Through this, the study aims to contribute to the broader understanding of the environmental impacts of economic and policy decisions in these nations.

When we substitute the variables, we used in our model, the following equation is created:

$$CO_2 = a + \beta\,(GDPC) + \beta\,(REC) + \beta\,(FDI) + \mu i \qquad (2)$$

The econometric models featured in this study encompass the Pooled Ordinary Least Squares (OLS) model, which is a fundamental approach in econometric analysis. The key principle of Pooled OLS is to minimize the sum of squared residuals, which essentially measures the difference between the observed and predicted values of the dependent variable. This approach is grounded in the assumption that both the coefficient and the intercept in the model are constant over time and across different entities, such as countries in this case.

The Pooled OLS model is represented mathematically as $Y=X\beta+\varepsilon$. In this equation, $Y$ denotes the dependent variable, $X$ represents the matrix of independent variables, $\beta$ is the vector of coefficients to be estimated, and $\varepsilon$ signifies the error term. The error term encompasses the statistical noise, capturing those disturbances that are not explained by the independent variables over time and across the cross-section.

The assumption of constant coefficients and intercepts across time and entities implies that the impact of the independent variables on the dependent variable is uniform across all units and does not vary over the period of study. This makes the Pooled OLS model particularly suitable for datasets where the assumption of homogeneity holds true. In the context of this study, it implies that the relationship between variables such as GDP per capita, renewable energy consumption, foreign direct investment, and $CO_2$ emissions is consistent across the nine developed European countries and remains stable over the 18 years.

However, it's important to note that while Pooled OLS is a powerful tool for analysis, its effectiveness is contingent on the validity of its underlying assumptions. If these assumptions do not hold – for instance, if the relationship between the variables changes over time or differs across countries – then alternative models like Fixed Effects or Random Effects might be more appropriate to capture the nuances of the data. In this study, the choice of Pooled OLS as one of the econometric models signifies a preliminary hypothesis that the relationships being studied are stable and consistent across the sample.

In addition to the Pooled Ordinary Least Squares (OLS) model, this study incorporates three other econometric methods to provide a comprehensive analysis of the data.

The second method employed is the Pooled Least Squares Robust (OLSR). This method is an extension of the standard Pooled OLS but with an emphasis on robustness. The OLSR approach adjusts the standard errors of the coefficients to account for potential l heteroskedasticity or autocorrelation within the error terms. This adjustment makes the OLSR model more reliable in cases where the standard assumptions of homoscedasticity (constant variance of error terms) in OLS might be violated. Essentially, OLSR provides a safeguard against potential inconsistencies in the data, ensuring that the model's estimates remain robust even in the presence of irregularities in the error distribution.

The third method is the Fixed Effect Model (FEM). Unlike Pooled OLS and OLSR, which assume constant intercepts across all cross-sections (countries in this study), FEM allows the intercept to vary for each cross-section. This variation means that FEM can accommodate unique, unobserved characteristics specific to each country that might affect the dependent variable. By allowing for these individual-specific intercepts, FEM can control for time-invariant heterogeneity, making it particularly useful for panel data where these individual effects are likely to be present and significant.

Lastly, the study incorporates the Random Effect Model (REM). REM differs from FEM in its treatment of the intercepts. While FEM treats these intercepts as fixed and unique to each cross-section, REM considers them as random variables. This approach assumes that these individual-specific effects are random and uncorrelated with the independent variables of the model. The random effects are also considered to be independent of the error term. REM is particularly useful when the variation across entities (countries) is assumed to be random and not systematically related to the independent variables in the model.

Each of these models – Pooled OLS, OLSR, FEM, and REM – offers a unique perspective and handles the data in different ways, accounting for various potential issues and characteristics of panel data. The selection of these models allows for a more nuanced and comprehensive analysis, ensuring that the study's conclusions are robust and account for the complexities inherent in panel data, especially when examining diverse countries over an extended period.

In the context of the Random Effect Model (REM), a key assumption is that the intercepts are independent of the error term and are also mutually independent among different entities (countries, in this study). This assumption is crucial in defining the structure and interpretation of the REM. The mathematical representation of the REM can be expressed as $Yit=Xit\beta+Zi\pi+\varepsilon it$. In this equation, $Yit$ represents the dependent variable for country $i$ at time $t$. $Xit$ is the matrix of independent variables, and $\beta$ is the vector of coefficients that are estimated in the model. These components are similar to what is found in the Pooled OLS model. The distinct feature of REM is the inclusion of $Zi\pi$, where $Zi$ represents the country-specific random effects, and $\pi$ is the vector of coefficients associated with these random effects. The term $\varepsilon it$ denotes the usual error term. The assumption that the intercepts (contained within $Zi\pi$) are independent of the error term ($\varepsilon it$) and are mutually independent across the countries is fundamental to the REM. This means that the unique characteristics of each country, captured by the random intercepts, are not systematically related to the variables of interest in the model and are randomly distributed across the countries.

This setup allows REM to account for unobserved heterogeneity that is not captured by the independent variables but may still influence the dependent variable. By treating these country-specific effects as random, REM provides a way to consider this heterogeneity without making the more stringent assumptions of the Fixed Effect Model, which treats these effects as fixed and unique to each country. In essence, this modeling approach enables a balanced consideration of both the observed variables and the unobserved individual characteristics in a way that acknowledges their potential random variation and independence from the model's error terms. This feature of REM makes it particularly valuable in panel data analysis where unobserved heterogeneity is a concern, but where the fixed effects approach may not be entirely appropriate or feasible.

The Hausman test plays a critical role in this study as a diagnostic tool to determine the most appropriate model between the Fixed Effect Model (FEM) and the Random Effect Model (REM) in panel data analysis. This test is specifically designed to address the issue of model selection in the presence of potential endogeneity of regressors in panel data.

Endogenous regressors in a regression model refer to predictor variables that are correlated with the error term. This correlation can lead to biased and inconsistent estimates in regression analysis. In panel data, where both FEM and REM are viable options, choosing the right model is crucial because it directly affects the reliability of the study's findings.

The Hausman test operates by comparing the coefficients obtained from both FEM and REM. The null hypothesis of the test posits that the preferred model is REM because it is more efficient (i.e., it has a smaller variance of the estimator) under the assumption that the unique errors (country-specific effects) are uncorrelated with the regressors. In other words, the REM assumes that the individual-specific effects are random and do not systematically affect the independent variables.

On the other hand, the alternative hypothesis suggests that if the unique errors are correlated with the regressors, FEM should be used. FEM is considered at least as consistent as REM, even if it is less efficient. This consistency stems from the fact that FEM explicitly controls for time-invariant characteristics, eliminating the bias that these unobserved characteristics could introduce if they were correlated with the regressors.

In practice, if the Hausman test indicates a significant difference between the coefficients estimated by FEM and REM, this suggests that the individual effects are correlated with the independent variables, and therefore, the FEM is the appropriate choice. Conversely, if the test finds no significant difference, it supports the use of REM, capitalizing on its greater efficiency.

Thus, the Hausman test is an essential component of this study's econometric analysis, providing a robust statistical basis for choosing between FEM and REM. This choice has important implications for the validity and reliability of the study's conclusions, particularly in understanding the relationships between variables like GDP per capita, renewable energy consumption, foreign direct investment, and $CO_2$ emissions in the context of developed European countries.

### 3.2 Objectives and hypotheses

The principal aim of this study is to conduct a thorough analysis of how renewable energy consumption, economic growth, and foreign direct investment influence carbon dioxide emissions in developed European countries, specifically during the period from 2002 to 2019. This timeframe is particularly significant as it covers nearly two decades, allowing for the observation of longer-term trends and effects.

Renewable energy consumption (REC) is a focal point of this study. As countries shift from traditional energy sources to more sustainable ones, understanding the impact of this transition on carbon dioxide emissions is crucial. The study seeks to quantify the extent to which increasing the use of renewable energy sources can mitigate the environmental impact of energy consumption.

Economic growth, measured by GDP per capita, is another critical variable. This aspect explores how the economic development of these countries correlates with their carbon emissions. The study aims to unravel the complexities of the relationship between economic prosperity and environmental sustainability, probing whether economic growth necessarily leads to increased carbon emissions or if developed nations have decoupled economic growth from environmental degradation.

Foreign direct investment (FDI) is also examined for its potential impact on carbon dioxide emissions. FDI can be a catalyst for technology transfer and economic development, but its role in influencing environmental practices and policies is multifaceted. The study investigates whether FDI contributes to higher carbon emissions, perhaps through increased industrial activity, or if it promotes the adoption of cleaner and more efficient technologies, thereby reducing emissions.

By analyzing these variables over a significant period, the study provides valuable insights into the dynamic interplay between renewable energy use, economic growth, and foreign investment in the context of environmental impact. This examination is especially pertinent for developed European countries, which are often at the forefront of implementing policies and technologies aimed at sustainable development. The findings of this study are expected to offer important implications for policymakers, businesses, and environmentalists as they strive to balance economic objectives with the pressing need to address climate change and reduce carbon emissions.

Hypotheses raised to achieve the study objectives are as follows:

**$H_0$:** The consumption of renewable energy (REC) reduces the emission of carbon dioxide ($CO_2$).

**Ha:** The consumption of renewable energy (REC) increases the emission of carbon dioxide ($CO_2$).

**Ho:** An increase in GDP per capita, reduces carbon dioxide emissions ($CO_2$).

**Ha:** An increase in GDP per capita, increases carbon dioxide emissions ($CO_2$).

**Ho:** Foreign direct investment (FID) reduces carbon dioxide emissions ($CO_2$).

**Ha:** Foreign direct investment (FDI) increases carbon dioxide emissions.

## 4. RESULTS

In this study, to comprehensively analyze the impact of various factors on carbon dioxide emissions, cross-country regressions and a dynamic panel model were employed. This methodological approach is particularly effective in capturing both the individual characteristics of each country and the temporal dynamics over the study period. The analysis incorporates annual data sourced from the World Bank database (WB), renowned for its reliability and comprehensiveness in providing global economic and environmental data. The study focuses on nine developed European countries, carefully selected for their economic significance and environmental policies. These countries include Germany, the United Kingdom, France, Italy, Spain, the Netherlands, Switzerland, Turkey, and Poland. The choice of these nations provides a diverse yet relevant sample for examining the developed European context, ensuring that the findings are both representative and applicable to similar economies. The time frame for the study spans 18 years, from 2002 to 2019. This extensive period allows for an in-depth exploration of long-term trends and patterns, offering insights into how changes over time in economic, environmental, and investment policies have influenced carbon dioxide emissions in these countries. To facilitate this analysis, a range of variables were included in the sample. These variables were meticulously chosen for their relevance and potential impact on carbon dioxide emissions. This structured approach, combining a dynamic panel model with cross-country regression analysis, provides a robust framework for investigating the complex interactions between economic growth, renewable energy consumption, foreign direct investment, and carbon dioxide emissions. By integrating data from a reliable source like the World Bank, the study ensures the accuracy and credibility of its findings, offering valuable contributions to the discourse on sustainable development and environmental policy in developed European countries.

### 4.1 Tables

Table 1 below outlines these variables, detailing their specific measures and the sources from which they were derived:

**Table 1.** Definition of variables

| Definition | Variable | The Measure | Source |
|---|---|---|---|
| $CO_2$ emissions | CO | Metric tons per capita (annual %) | WB |
| GDP per capita growth | GDPC | (Annual %) | WB |
| Renewable energy consumption | REC | (% of total final energy consumption) | WB |
| Foreign direct investment, net inflows | FDI | (% of GDP) | WB |

To effectively convey the fundamental attributes of the dataset used in this study, descriptive statistics have been presented. These statistics play a crucial role in summarizing and characterizing the main features of the dataset, encompassing aspects like central tendency, variability, and distribution. By providing a comprehensive overview of the data, descriptive statistics serve as a foundational step in the analysis, aiding in the identification of key patterns and potential relationships within the dataset.

Central tendency, one of the primary aspects of descriptive statistics, involves metrics such as mean, median, and mode. These measures give insights into the 'average' or most common values observed in the dataset, offering a snapshot of typical outcomes or trends. For instance, the mean GDP per capita or average renewable energy consumption across the countries in the study period can be indicative of general economic conditions or energy policy trends in these nations.

Variability, another critical aspect, is captured through measures like standard deviation and variance. These statistics describe the spread or dispersion of data points around the mean, indicating how much variation or inconsistency exists within the dataset. A high variance in $CO_2$ emissions, for example, might suggest significant differences in environmental impact across the countries or over time.

Distribution is also examined, often through histograms or frequency distributions. This aspect of descriptive statistics reveals the shape of the data distribution, showing how data points are spread across the range of possible values. Understanding the distribution helps in identifying outliers, skewness, or other peculiarities in the data, such as unusually high or low levels of foreign direct investment in certain years or countries.

Overall, descriptive statistics provide an essential preliminary overview of the dataset. They lay the groundwork for more detailed and complex analyses, such as econometric modeling, by offering initial insights into the nature and characteristics of the data under study. By summarizing key features of the dataset, descriptive statistics help researchers and readers alike to understand the basic context and underlying patterns, setting the stage for deeper investigation into the relationships and impacts of renewable energy consumption, economic growth, foreign direct investment, and carbon dioxide emissions in developed European countries.

For summarizing and describing the main characteristics of a dataset, such as its central tendency, variability, and distribution we have presented descriptive statistics which provide an overview of the data and aid in the identification of patterns and relationships. Further, the table below presents the descriptive statistics of the study variables for all countries included in the sample, respectively for nine countries during the 18 years, a total of 162 observations. The countries of the study model have a $CO_2$ emission value of 1.89, positive economic performance at an average of 1.77%, Renewable energy consumption reaches an average of 11.36% of total final energy consumption, and Foreign Direct Investment takes an average of 5.93% as % of GDP. Worth noting in 2018 Netherlands has resulted in a considerable decrease in FDI, especially by 29.90%.

**Table 2.** Descriptive statistics of the variables Used

| Variables | Obs. | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| $CO_2$ | 162 | 1.89 | 0.29 | 1.14 | 2.35 |
| GDPC | 162 | 1.48 | 2.51 | -6.01 | 9.73 |
| REC | 162 | 11.36 | 5.54 | 0.93 | 24.99 |
| FDI | 162 | 5.93 | 11.88 | -29.90 | 71.34 |

Source: STATA Author's Calculation; Data from the World Bank (WB)

Further, Table 2 presents the correlation coefficient between the independent variables and the dependent variable. The matrix depicts the relationship that exists between certain variables. Moreover, based on the correlation results, two variables namely, GDP per capita (r=0.12) and Renewable energy consumption (r=0.67), have a negative relationship with $CO_2$ emissions, while the other variable (Foreign Direct Investment) has a positive relationship with $CO_2$ emissions.

**Table 3.** Matrix of correlations

| Variables | CO | GDPC | REC | FDI |
|---|---|---|---|---|
| CO | 1.00 | | | |
| GDPC | -0.12 | 1.00 | | |
| REC | -0.67 | 0.01 | 1.00 | |
| FDI | 0.33 | -0.01 | -0.24 | 1.00 |

Source: STATA Author's Calculation; Data from the World Bank

After the presentation of the correlation results (Table 3), the summary analysis of the regression results is presented below (Table 4).

**Table 4.** Analysis of regression results

| Variables | OLS | OLSR | FE | RE |
|---|---|---|---|---|
| | $CO_2$ | $CO_2$ | $CO_2$ | $CO_2$ |
| GDPC | -0.0133* | -0.0133 | -0.000188 | -0.000260 |
| t-stat | (-2.00) | (-1.58) | (-0.08) | (-0.11) |
| REC | -0.0334*** | -0.0334*** | -0.0370*** | -0.0370*** |
| t-stat | (-10.75) | (-16.74) | (-23.31) | (-23.54) |
| FDI | 0.00436** | 0.00436*** | 0.000533 | 0.000557 |
| t-stat | (3.00) | (4.80) | (0.95) | (1.00) |
| cons | 2.265*** | 2.265*** | 2.309*** | 2.309*** |
| | (52.82) | (73.97) | (119.30) | (26.33) |
| R-squared | 49.40% | 49.40% | 45.87% | 45.91% |
| Observations | 162 | 162 | 162 | 162 |
| Hausman test=0.98 | | | | |
| VIF=1.04 | | | | |

Notes: ***Statistically significant at 1% level, **statistically significant at 5% level, *statistically significant at 10% level
Source: Author's calculation

Table 4 above shows the results of four econometric models. Moreover, the random effect seems to be more appropriate in this topic by taking into consideration the results of the Hausman test, based on the P value that is higher than 0.05, by means that the difference in the coefficient is not systematic although, the interpretation of the results.

Multicollinearity is a concept that refers to the correlation of several independent variables in a model. Additionally, the VIF test is presented to test the data for multicollinearity further, according to the data generated, multicollinearity doesn't exist, since the average of the VIF is less than 5.

Based on the results generated using the STATA software, renewable energy consumption (REC) has a negative impact on $CO_2$ emissions, with a coefficient of (0.0370). For a 1% increase in renewable energy consumption, carbon dioxide emissions are reduced by 0.037%, similar to the other studies such as Nachrowi [19], and is significant at the 1% level of importance, which shows that renewable energy consumption has an impact on improving the quality of the environment in the developed countries of Europe these findings are consistent with the author Hao [20]. Also, according to study of Bai [21], renewable energy is useful for reducing local carbon emissions. GDP per capita has a negative impact on $CO_2$ emissions with a coefficient of (-0.000260) [22]. For a 1% increase in GDP per capita, carbon dioxide emissions are reduced by 0.0002% and do not indicate a level of significance. Foreign Direct Investment has a positive impact on $CO_2$ emissions, with a coefficient of 0.000557, and does not indicate a level of significance (Table 5).

**Table 5.** Hypothesis testing

| H | Hypothesis | Testing | Rationale |
|---|---|---|---|
| Ho | The consumption of renewable energy reduces the emission of carbon dioxide. | Accepted | Since the renewable energy consumption coefficient is negative, we accept the null hypothesis. |
| Ha | The consumption of renewable energy increases the emission of carbon dioxide. | Rejected | Since the coefficient of renewable energy consumption is negative, we reject the alternative hypothesis. |
| Ho | An increase in GDP per capita reduces carbon dioxide emissions. | Accepted | Since the coefficient of GDP per capita is negative, we accept the null hypothesis. |
| Ha | An increase in GDP per capita increases carbon dioxide emissions. | Rejected | Since the coefficient of GDP per capita is negative, we reject the alternative hypothesis |
| Ho | Foreign direct investment reduces carbon dioxide emissions. | Rejected | Since the foreign direct investment (FDI) coefficient is positive, we reject the null hypothesis. |
| Ha | Foreign direct investment increases carbon dioxide emissions. | Accepted | Since the coefficient of foreign direct investment (FDI) is positive, we accept the alternative hypothesis. |

## 5. CONCLUSIONS

The renewable energy sector is considered to be one of the most active, quickly evolving, and changing segments of the global economy and, has become the engine of economic growth around the world as a result of technical advancements, cost reductions, and the enormous influence of new finance structures. The adoption of clean energy technologies is a strategy that has gained widespread support for addressing the threat posed by climate change. Additionally, the motivation of the study is to determine whether the use of renewable energy will be beneficial to ensure sustainable economic growth. Based on the hypotheses included in the study we confirm that the consumption of renewable energy reduces the emission of carbon dioxide ($CO_2$).

In terms of the global scene, policymakers should support a global initiative to advance energy efficiency and renewable energy, as well as introduce the appropriate incentive mechanisms for the development and market accessibility of renewable energy. Further, cooperation between certain sectors in the development of renewable energy markets could begin with sharing information about ongoing projects, technologies, financing, and investment strategies. To develop such a mechanism to promote renewable energy investment for low-carbon growth in most economies, coordination between governments, energy planners, international cooperation organizations, and related organizations is thought to be extremely essential. Furthermore, renewable energy plays a key role in reducing carbon dioxide emissions by replacing traditional energy sources with sustainable sources. Based on our empirical research for the period from 2002 to 2019 in the nine developed countries of Europe, considered in the sample, we have understood that with the increase in GDP per capita, there is a tendency to reduce carbon dioxide also with the increase of renewable energy consumption, carbon dioxide emissions are reduced, and for every 1% increase in renewable energy consumption, carbon dioxide emissions are reduced by 0.037%. Although foreign direct investments (FDI), have a positive relationship with carbon dioxide emissions, however, this relationship is not statistically significant. Our recommendation for future research in this domain is to pursue a more expansive approach by incorporating a broader set of countries, extending the temporal scope, and introducing additional variables into the analysis. This suggestion stems from a desire to deepen and widen the understanding of the complex dynamics between renewable energy consumption, economic growth, foreign direct investment, and carbon dioxide emissions. Expanding the geographical scope to include more countries could provide a more comprehensive global perspective, allowing for comparisons and contrasts between different economic and environmental contexts. Including countries with varying levels of development, policy frameworks, and environmental challenges would enrich the analysis, offering insights into how these factors interact in diverse settings.

Extending the time period of the study is also crucial. A longer timeframe would enable the observation of longer-term trends and the effects of policy changes over time. This could be particularly enlightening in understanding how shifts in energy policies, economic cycles, and international investment flows influence environmental outcomes over decades.

Incorporating additional variables into the sample could further enhance the study's depth. Variables such as technological innovation, energy efficiency measures, policy initiatives, and public awareness of environmental issues could provide a more nuanced understanding of the factors driving carbon dioxide emissions and the effectiveness of strategies to mitigate them. It is important to note, however, that the expansion of the study in the current context was limited by data availability for certain years and countries. Data limitations can pose significant challenges in conducting comprehensive and robust analyses, especially in cases where consistent and reliable data are not readily available or are absent for key years or countries.

Despite these constraints, the commitment to refining and broadening the scope of the analysis remains a priority. Future studies should continue to strive for a more inclusive and extensive examination of these critical issues, within the bounds of data availability. The goal is to build upon the existing research, overcoming data limitations where possible, to provide richer, more informative insights that can guide policymakers, businesses, and communities in their efforts to achieve sustainable economic growth while mitigating environmental impacts.

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## NOMENCLATURE

| | |
|---|---|
| OLS | Ordinary Least Squares |
| OLSR | Ordinary Least Squares Robust |
| $CO_2$ | Carbon dioxide |
| REM | Random Effect Method |
| FEM | Fixed Effect Method |
| $N_2O$ | Nitrous Oxide |
| $CH_4$ | Methane |
| FDI | Foreign Direct Investment |
| EU | European Union |
| REC | Renewable Energy Consumption |