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Analysis of Greenhouse Gas Emission Reduction Factors in the Context of the Transition to Renewable Energy

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ABSTRACT

In the current context of climate change, the transition to renewable energy sources is important for reducing greenhouse gas emissions and achieving sustainable development goals. This study analyzes the economic and energy factors influencing greenhouse gas emissions and their role in facilitating the transition to renewable energy. The methods used consist of a literature review on the transition to renewable energy from a GHG emission reduction perspective, database consolidation and econometric modeling. The results will highlight that energy import dependency and energy-related tax revenues have a significant impact on greenhouse gas emissions, suggesting the need for policies that promote energy independence and tax efficiency. The results will be useful for policy makers, highlighting the need for strategic interventions to maximize the benefits of the energy transition, respectively the implementation of integrated policies that support both the reduction of greenhouse gas emissions and the use of renewable energy sources, which are necessary to ensure a sustainable and climate resilient future.

1. Introduction

Europe is in a critical period of energy transition, with the main objective of significantly reducing greenhouse gas emissions to combat climate change and promote sustainability. European Union energy and environment policies, such as the European Green Deal, set ambitious targets of being climate neutral by 2050 and reducing emissions by at least 55% by 2030 compared to 1990 levels. This transition requires a reconfiguration of national energy systems, a rapid uptake of green technologies and a strong commitment from all Member States. The reconfiguration of national energy systems is an essential step in this transition. EU Member States need to modernize their energy infrastructure to integrate renewable energy sources such as solar, wind and hydro. This requires the development of smart grids that enable more efficient management of energy flows, optimal integration of variable renewable energy sources and rapid response to energy supply and demand. Smart grids help reduce energy losses and improve reliability and security of supply. Increased energy storage capacities are important to compensate for the variability of renewables and to ensure a steady supply. Modernization of distribution networks is needed to handle bi-directional energy flows and to integrate distributed generation of renewable energy from prosumers. The rapid uptake of green technologies is vital to achieve greenhouse gas reduction targets. Supporting research and development of new green technologies, including advanced renewable energies, sustainable materials and low-emission industrial processes, is a priority for the transition to climate neutrality. Funding for research and innovation projects must be a priority to ensure the necessary technological progress and to boost the competitiveness of European industry globally. In this context we aim to analyze the factors of greenhouse gas emission reduction in the context of switching to renewable energy. The objectives of the study are:

O1: literature review on economic development models in the context of the transition to climate neutrality;

O2: strengthening the database for the study of sustainable energy progress in the European Union and its relation to economic development;

O3: conceptualization of the economic model of transition to green energy;

O4: applying the Kruskal-Wallis test of independence to quantify the correlation of Member States' results in the context of the transition to climate neutrality;

O5: dissemination of the results obtained

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The article continues with the literature review on economic development models in the context of the transition to climate neutrality; the presentation of the methodology and results obtained and the formulation of economic development policies in the context of the transition to climate neutrality in the conclusions section.

2. Literature review

The transition to renewable energy sources is of major importance in the context of climate change and global efforts to reduce greenhouse gas emissions. As the pressure on traditional energy resources continues to grow and the negative effects of climate change become increasingly evident, it is almost imperative that current energy systems are reassessed and transformed. This recognition by both the scientific community and policy makers has stimulated a growing interest in the literature exploring the solutions and strategies needed to ensure an efficient and sustainable transition to renewable energy sources.

The transition to renewable energy sources is essential to mitigate the impacts of climate change and ensure global energy security. As conventional energy resources such as fossil fuels are depleting and contributing significantly to greenhouse gas emissions, renewable energy offers a viable and sustainable solution in topical research (Deshmukh et al., 2023; Holechek et al., 2022; Lu et al., 2020; Arifur Rahman et al., 2024). Various recent academic studies (Habiba et al., 2022; Khan et al., 2022; Raihan, Begum, et al., 2022; Woon et al., 2023; Z. Zhang et al., 2024) emphasizes the importance of reducing carbon emissions and highlights the economic and social benefits of adopting renewables. Some studies also show that the transition to clean energy not only supports efforts to combat climate change, but also stimulates technological innovation and job creation (X. H. Chen et al., 2023; Kwilinski et al., 2024; Raihan, Muhtasim, et al., 2022; Rehman et al., 2024). A coherent policy and strategic investments in renewable energy infrastructure are therefore considered imperative for long-term sustainable development.

The use of renewable energy sources, such as solar, wind, hydro and geothermal energy, plays a key role in reducing emissions of carbon dioxide (CO2) and other greenhouse gases, which are the main contributors to climate change (Ghezelbash et al., 2023; Paraschiv & Paraschiv, 2023; Abidur Rahman et al., 2022). According to research from the International Renewable Energy Agency [IRENA], these energy sources have the potential to reduce global CO2 emissions by up to 70% by 2050 compared to current levels (International Renewable Energy Agency, 2021). This significant reduction could have a positive impact on the environment, mitigating the effects of global warming and helping to stabilize the global climate. Furthermore, by decreasing dependence on fossil fuels, air quality is significantly improved, with direct public health benefits such as reduced incidence of respiratory and cardiovascular disease (Ofremu et al., 2024; Y. Zhang et al., 2023). Studies show that the transition to clean energy could prevent millions of premature deaths each year from air pollution (Galimova et al., 2022; D. Wu et al., 2023; W. Zhang et al., 2021).

Many researches (Carfora et al., 2022; Luty et al., 2023; Mara et al., 2022) have shown that investing in renewable energy sources contributes significantly to energy independence, thus reducing countries' dependence on energy imports and strengthening their energy security. This transition can also boost economic growth by creating jobs in the green energy sector, such as in the production, installation and maintenance of renewable technologies. Studies show that the renewable energy industry has already generated millions of jobs globally, and this trend is expected to increase as the energy transition intensifies (Akaev & Davydova, 2023; Hassan, Viktor, et al., 2024). Renewables offer long-term price stability, with significantly lower and more predictable operating and maintenance costs compared to fossil fuels, whose markets are often volatile and susceptible to price fluctuations due to geopolitical instabilities and supply variability (Alola et al., 2022; Androniceanu & Sabie, 2022; Fu et al., 2024; Su et al., 2023). These economic characteristics of renewables not only facilitate a more sustainable transition, but also provide a sound economic basis for long-term development.

Technological progress in renewable energy plays an extremely important and useful role in stimulating innovation and research, leading to the development of more efficient and cost-effective energy solutions, as supported by many expert studies (Ahmed et al., 2024; Bogdanov et al., 2021; Dumitriu & Dragomir, 2021; Kylili et al., 2021; Wen et al., 2022). Emerging technologies such as high-efficiency solar panels, advanced wind turbines and energy storage solutions have the potential to fundamentally transform global energy systems. Expert studies highlight that the integration of renewable energy sources facilitates the deployment of smart grids, which play a key role in optimizing energy distribution and consumption (Ahmad et al., 2022; Barone et al., 2023; Hassan, Hsu, et al., 2024; Tan et al., 2021). Smart grids allow real-time monitoring and management of energy flows, improving the efficiency of energy systems and ensuring better adaptation to the variability of renewable sources. This increased adaptability and flexibility promotes better use of available resources and helps reduce energy losses.

There are a number of technical and economic challenges regarding the deployment of the necessary infrastructure for the use of renewable energy sources, often involving high upfront costs, which can be a significant barrier to the widespread adoption of these technologies (L. Chen et al., 2024; Gajdzik et al., 2023; Hassan et al., 2023; Seetharaman et al., 2019). Various researchers point out that investment in renewable energy requires robust financial planning and support from the public and private sector to overcome these economic obstacles (Qadir et al., 2021; Tache, 2010; Wei et al., 2022; H. Wu, 2023; L. Zhang et al., 2022). The intermittency of energy sources such as solar and wind, due to their dependence on weather conditions, requires the development of efficient storage solutions and smart grid technologies to ensure the stability and reliability of energy supply (Ayesha et al., 2023; Bărbulescu et al., 2021; Kataray et al., 2023; Khalid, 2024).

On the other hand, there are also many opportunities to support the energy transition through effective government policies. The implementation of subsidies and fiscal incentives can encourage investment in renewable energy, thus facilitating economic growth in this sector (Koengkan et al., 2024; Meng et al., 2022; Yan et al., 2023). Tough carbon regulations can also speed up the transition to clean energy sources, encouraging companies to adopt more sustainable technologies and reducing dependence on fossil fuels. Studies show that such policy measures not only promote economic development and environmental protection, but also help create a stable and predictable framework for renewable energy investors (Abba et al., 2022; Bashir et al., 2022; Shahzad et al., 2021; Żuk & Żuk, 2024).

The transition to renewable energy sources is essential to address the challenges of climate change and ensure a sustainable future. This transition is not only an environmental necessity but also a significant economic and technological opportunity. With the right policies and investment in research and development, society can turn today's challenges into an opportunity to create a more sustainable and equitable energy system for the future.

To benefit from an effective transition to renewable energy sources, countries need to ensure a significant increase in investment in research and development of green technologies, which will stimulate innovation and reduce the costs associated with implementing these solutions. Education and public awareness of the benefits of renewable energy are also key to gaining the social and political support for change. International cooperation plays a significant role in facilitating the exchange of knowledge and resources, thereby accelerating the adoption of green technologies globally. The development and integration of energy storage technologies is fundamental to address the intermittency of renewable sources, ensuring a stable energy supply, and the deployment of smart energy grids optimizes the distribution and use of renewable energy, improving the efficiency and reliability of energy systems.

3. Methodology

In order to identify the economic evolution in climate change, we have developed an econometric model based on multiple linear regression that captures the influence of the evolution of energy indicators on economic growth from the perspective of an increasingly resource consuming economy and confronted with the requirements imposed by the European authorities on the transition to climate neutrality and limitation of greenhouse gas emissions. The proposed model is based on the study of the energy and economic indicators reported by Eurostat for the 27 Member States of the European Union for the period 2010-2022. For this purpose the following indicators were used:

- GDP- Real gross domestic product (Eurostat, 2024d);
- FENC- Final energy consumption (Eurostat, 2024b);
- ENPR-Energy productivity (Eurostat, 2024a);
- REWEN- Share of renewable energy in gross final energy consumption (Eurostat, 2024e);
- NGRGEM- Net greenhouse gas emissions (Eurostat, 2024c).

The following working hypotheses have been defined:

H1: Reliance on primary energy is not economically efficient and that investments in reducing energy consumption could have a positive impact on the economy;

H2: Sustainable economic growth requires a significant improvement in energy efficiency in all sectors of the economy and in household energy use. We applied the method of least squares for the centralized data series using the database concatenation method and designed the multiple linear regression for the economic model of transition to green energy, the model equation being defined based on the unstandardized coefficients calculated using SPSS.

$$GDP = -25.924 * FENC + 3627.880 * ENPR + 0.214 * REWEN + 22.965 * NGRGEM - 1265.168$$

From equation 1 it can be seen that the coefficient of the indicator on final primary energy consumption is negative. This shows that an increase in FENC by one unit is associated with a decrease in GDP by 25,924 units. It thus proves working hypothesis 1, i.e. that reliance on primary energy is not economically efficient and that investments in reducing energy consumption could have a positive impact on the economy. In the European context, this reflects the transition towards more efficient and cleaner energy sources, in line with EU energy and climate change policies from 2010-2022.

The significant positive coefficient of the Energy productivity indicator shows that an increase in energy productivity by one unit is associated with an increase in GDP by 3627,880 units. It thus demonstrates working hypothesis 2 that sustainable economic growth requires a significant improvement in energy efficiency in all sectors of the economy and in household energy use. Over the period analyzed, Europe has invested significantly in energy efficiency technologies, which has contributed to GDP growth and sustainability goals.

Regarding the share of renewable energy, the positive, statistically insignificant coefficient indicates that an increase in the share of renewable energy has a marginal positive impact on GDP. However, in the long term, increasing the use of renewable energy is essential for economic sustainability and reducing greenhouse gas emissions. This is in line with the European energy strategy to promote renewable energy sources. At the same time, the analysis of net greenhouse gas emissions shows a positive coefficient (22.965), which suggests that the increase in net greenhouse gas emissions is associated with an increase in GDP. This may reflect the fact that in some economic sectors, growth in economic activities is still linked to carbon emissions. However, European policies from 2010-2022 have aimed to reduce these emissions by implementing strict regulations and promoting green technologies. The model summary presented in Table 1 shows that the model is medium statistically significant with a coefficient of determination value of 57% which means that in the context of the transition to climate neutrality economic growth may be decelerated by some particularities of the energy sector such as greenhouse gas emissions, dependence on fossil fuels, non-widespread deployment of renewable energy technologies and lack of energy infrastructure for the mass use of renewable energy.

Table. 1. Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	0.758	0.575	0.570	11194.006	0.575	116.852	4	346	0.000	1.730
a. Predictors: (Constant), NGRGEM, FENC, ENPR, REWEN										
b. Dependent Variable: GDP										

Source: Elaborated by authors

According to the data in Table 1, the F-function level is 116 points for a regression freedom of 4 units and a Reyidurilo of 346 units and an error representation level below the 5% threshold.
Table 2 presents the results of the Anova test.

Table. 2. ANOVA

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	58569083375.412	4	14642270843.853	116.852	.000[b]
Residual	43355795997.807	346	125305768.780		
Total	101924879373.219	350			
a. Dependent Variable: GDP					
b. Predictors: (Constant), NGRGEM, FENC, ENPR, REWEN					

Source: Elaborated by authors

The F-value of 116.852 suggests that the independent variables as a whole significantly explain the variability in GDP. The p-value associated with the F-Statistic (0.000) indicates that the results are highly statistically significant. This means that there is a very low probability that the observed relationships are due to chance, confirming that the independent variables have a significant impact on GDP. The ANOVA analysis underlines the importance of efficient energy policies and the transition to sustainable energy sources to support economic growth in Europe. This reflects Europe's continued efforts to balance economic growth with environmental sustainability and to achieve long-term climate goals.

Figure 1 shows the histogram of the dependent variable showing the disparities in economic developments in the context of the transition to climate neutrality.

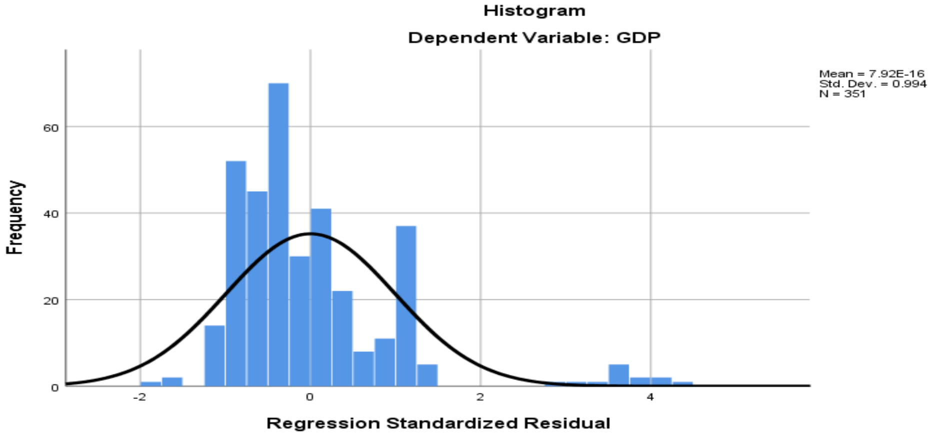


Figure. 1. Model histogram
Source: Elaborated by authors

The histogram shown in Figure 1 shows the frequency distribution of the standardized residuals. The histogram suggests that the standardized residuals follow a normal distribution, which is a prerequisite for the validity of the statistical inferences made from the regression model. This indicates that the regression model is well specified. Given that the regression model is well fitted and the residuals are normally distributed, we can be confident in the conclusions drawn about the impact of energy variables on GDP in the European context. This underlines the relevance and importance of pursuing efficient and sustainable energy policies to support economic growth in Europe.

The proposed model thus becomes validated under the condition of the transition to climate neutrality by coherently identifying the disparities associated with the transition between European countries and the vulnerabilities associated with greenhouse gas emission problems. In the context of European policies in the period 2010-2022, the results suggest that emission reduction measures must be an integral part of a broader economic and energy strategy, taking into account the multiple interdependencies between economic factors.

4. Results and discussions

In the European context, the period 2010-2022 was marked by significant efforts to tackle climate change and promote a greener and more sustainable economy. Europe has invested in technologies that improve energy efficiency and reduce primary energy consumption. This has had a positive impact on GDP, as indicated by the coefficients for ENPR and FENC. Although the coefficient for REWEN is not statistically significant, the promotion of renewable energy remains a central pillar of European energy policies. The gradual increase in the share of renewable energy will have long-term economic benefits. European policies have aimed to reduce greenhouse gas emissions, although analysis shows that emissions are still associated with GDP growth. This underlines the need for continued efforts to decouple economic growth from carbon emissions.

The results emphasize the importance of energy efficiency policies and the promotion of renewables to support sustainable economic growth.

We used the Independent-Samples Kruskal-Wallis Kruskal-Wallis Test to determine the independence of the distribution of indicators across states as shown in Table 3.

Table. 3. Hypothesis Test Summary

No.crt	Null Hypothesis	Test	Sig.	Decision
1	The distribution of FENC is the same across categories of Country.	Independent-Samples Kruskal-Wallis Test	0.000	Reject the null hypothesis.
2	The distribution of NGRGEM is the same across categories of Country.	Independent-Samples Kruskal-Wallis Test	0.000	Reject the null hypothesis.
3	The distribution of GDP is the same across categories of Country.	Independent-Samples Kruskal-Wallis Test	0.000	Reject the null hypothesis.
4	The distribution of ENPR is the same across categories of Country.	Independent-Samples Kruskal-Wallis Test	0.000	Reject the null hypothesis.
5	The distribution of REWEN is the same across categories of Country.	Independent-Samples Kruskal-Wallis Test	0.000	Reject the null hypothesis.
Asymptotic significances are displayed. The significance level is .050.				

Source: Elaborated by authors

All Kruskal-Wallis tests had significant results (Sig. = 0.000), which led to the rejection of the null hypothesis for each variable. This indicates that there are significant differences in the distributions of the energy and economic variables studied between the different European countries. These differences underline the diversity of national policies and economic and energy and economic contexts in Europe. Over the period 2010-2022, these disparities were likely influenced by factors such as the level of economic development, available natural resources, government policies and the ability to invest in efficient and sustainable energy technologies.

Table 4 shows the result of the Kruskal-Wallis test for the primary energy final consumption indicator.

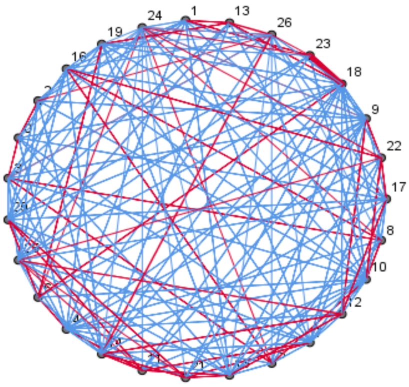
Table. 4. Result of the Kruskal-Wallis test for the primary energy end-use indicator

FENC across Country

Independent-Samples Kruskal-Wallis Test Summary

Total N	351
Test Statistic	348.755[a]
Degree Of Freedom	26
Asymptotic Sig.(2-sided test)	0.000

a. The test statistic is adjusted for ties.



Source: Elaborated by authors

According to Table 4 the Kruskal-Wallis test statistic value of 348.755, adjusted for linkages, is extremely high, suggesting significant differences in the distribution of energy consumption between the countries studied. This indicates that energy policies and energy consumption levels vary considerably between European countries. The p-value of 0.000 indicates that the observed differences in the distribution of NENC between countries are highly statistically significant. The probability that these differences are due to chance is virtually zero. The results suggest that energy policies adopted by different European countries are varied and influenced by specific local factors such as available natural resources, energy infrastructure and national priorities. Significant differences in primary energy consumption may also reflect different levels of energy efficiency and the uptake of renewable energy sources. Significant variations in primary energy consumption between countries can affect Europe's ability to meet its climate and greenhouse gas reduction targets.

Table 5 shows the result of the Kruskal-Wallis test for the net greenhouse gas emissions indicator.

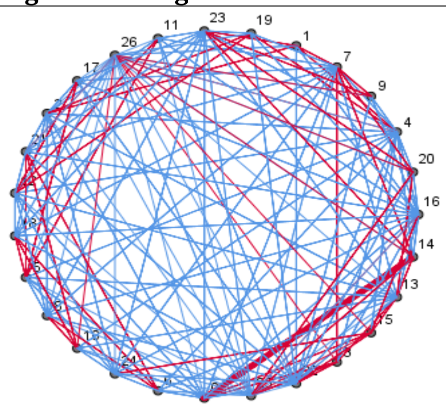
Table. 5. Result of the Kruskal-Wallis test for the net greenhouse gas emissions indicator

NGRGEM across Country

Independent-Samples Kruskal-Wallis Test Summary

Total N	351
Test Statistic	308.266a
Degree Of Freedom	26
Asymptotic Sig.(2-sided test)	0.000

a. The test statistic is adjusted for ties.



Source: Elaborated by authors

Table 5 presents the Kruskal-Wallis test statistic value of 308.266, adjusted for linkages, which is extremely high, suggesting significant differences in the distribution of net greenhouse gas emissions (NGRGEM) between the countries studied. This indicates that environmental policies and GHG emission levels vary considerably between European countries. Due to the asymptotically Sig. significant we can reject the null hypothesis that the distribution of net greenhouse gas emissions is the same across all country categories. The results suggest that the environmental policies adopted by different European countries are varied and influenced by specific local factors such as levels of industrialization, environmental infrastructure and national priorities. Significant differences in greenhouse gas emissions may also reflect countries' differing capacities to deploy abatement technologies and comply with environmental regulations. The significant disparities highlight the need for closer cooperation between EU Member States to harmonize environmental policies and promote sustainable practices.

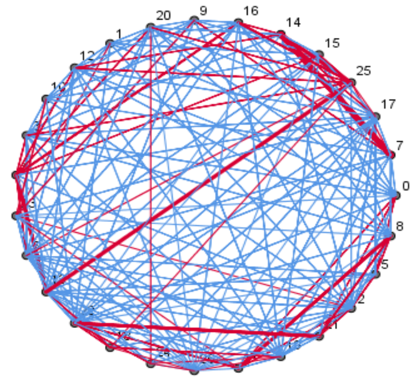
Table 6 shows the result of the Kruskal-Wallis test for the gross domestic product indicator.

Table. 6. Result of the Kruskal-Wallis test for the gross domestic product indicator

GDP across Country
Independent-Samples Kruskal-Wallis Test Summary

Total N	351
Test Statistic	341.574a
Degree Of Freedom	26
Asymptotic Sig.(2-sided test)	0.000

a. The test statistic is adjusted for ties.



Source: Elaborated by authors

Table 6 presents the results of the Kruskal-Wallis test which highlight the significant differences in GDP (Gross Domestic Product) between European countries. These variations reflect the diversity of national economies and underline the need for international cooperation to promote sustainable economic growth and achieve the Sustainable Development Goals at the European level. The results emphasize the importance of adopting common strategies and exchanging best practices to improve economic performance and reduce economic disparities in Europe.

Table 7 shows the result of the Kruskal-Wallis test for the energy productivity indicator.

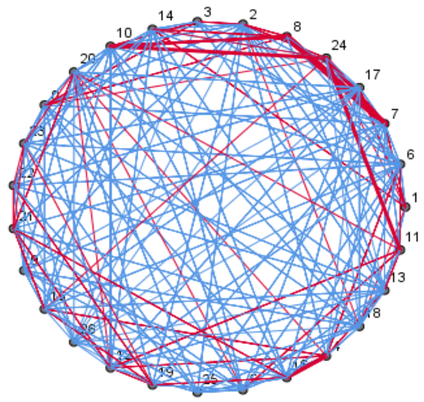
Table. 7. Result of the Kruskal-Wallis test for the energy productivity indicator

ENPR across Country

Independent-Samples Kruskal-Wallis Test Summary

Total N	351
Test Statistic	330.997a
Degree Of Freedom	26
Asymptotic Sig.(2-sided test)	0.000

a. The test statistic is adjusted for ties.



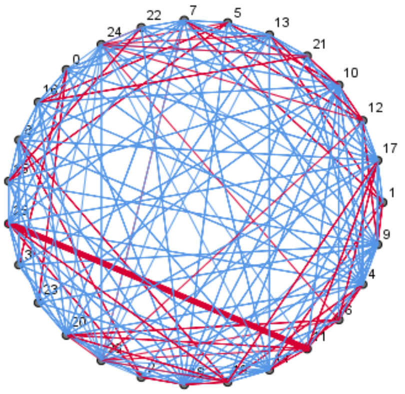
Source: Elaborated by authors

Table 7 shows the Kruskal-Wallis test statistic value of 330.997, adjusted for ties, is extremely high, suggesting significant differences in the distribution of energy productivity (ENPR) across the countries studied. This indicates that energy productivity levels vary considerably between European countries. The results suggest that energy efficiency policies adopted by different European countries are varied and influenced by specific local factors, such as energy infrastructure, government regulations and investments in energy efficient technologies. Significant differences in energy productivity may also reflect the different ability of countries to implement measures to increase energy efficiency and optimize the use of energy resources.

Table 8 shows the result of the Kruskal-Wallis test for the renewable energy share indicator.

Table. 8. Result of the Kruskal-Wallis test for the renewable energy share indicator

REWEN across Country Independent-Samples Kruskal-Wallis Test Summary	
Total N	351
Test Statistic	345.081a
Degree Of Freedom	26
Asymptotic Sig.(2-sided test)	0.000
a. The test statistic is adjusted for ties.	



Source: Elaborated by authors

The results in Table 8 suggest that the renewable energy promotion policies adopted by different European countries are varied and influenced by specific local factors such as available natural resources, energy infrastructure and government regulations. Significant differences in the share of renewable energy may also reflect the different capacity of countries to implement measures to increase the use of renewable energy and to integrate renewables into the national energy mix.

All Kruskal-Wallis tests indicate significant differences between European countries in terms of primary energy end-use consumption, greenhouse gas emissions, GDP, energy productivity and share of renewable energy. These differences reflect the diversity of national policies, available natural resources and economic and environmental priorities. The significant disparities underline the need for closer cooperation between EU Member States to harmonize energy and environment policies. Significant variations in the indicators studied may affect Europe's ability to achieve the goals of sustainable economic growth and reducing greenhouse gas emissions. Policies to stimulate innovation and the uptake of green technologies can help improve the energy and economic performance of European countries.

5. Conclusions

The transition to a renewable energy system is a major challenge but also a unique opportunity for Europe to secure a sustainable and prosperous future. The adoption and implementation of an integrated model to reduce greenhouse gas emissions requires a concerted effort by all actors involved, from governments and European institutions to the private sector and civil society. This fundamental transformation will not only contribute to achieving climate goals, but also to enhancing energy security and boosting sustainable economic development across the region.

Based on the data reported by Eurostat, we developed the new economic model of the transition to green energy, which proved to be statistically significant and relevant for the proposed research purpose. During the implementation of the model the working hypotheses were tested and validated, namely: Primary energy dependency is not economically efficient and that investments in reducing energy consumption could have a positive impact on the economy (H1); Sustainable economic growth requires significant improvements in energy efficiency in all sectors of the economy and in household energy use (H1). In order to achieve climate neutrality and promote sustainable economic development, it is essential to adopt integrated and well-coordinated public policies that address energy as well as economic and social aspects. These policies must encourage technological innovation, support the transition to renewable energy sources and ensure environmental protection while promoting economic growth. Public policies should prioritize investments in green energy infrastructure. These investments should target the development and modernization of smart grids, energy storage capacities and the infrastructure needed to integrate renewable energy sources. By deploying smart grids and advanced energy management systems, it will be possible to optimize energy consumption, reduce losses and improve the stability of the grids, thus contributing to increased energy efficiency and reduced greenhouse gas emissions. Policies to stimulate innovation and research in green technologies are important, and governments need to allocate significant funds to R&D projects targeting advanced renewable energy technologies, energy storage, green hydrogen and other innovative solutions. At the same time, a coherent legislative and regulatory framework is needed to support the transition to a green economy. This should include tax incentives for investments in renewable energy and energy efficient technologies, as well as penalties for activities with high greenhouse gas emissions.

In conclusion, public policies for economic development in the context of the transition to climate neutrality need to be comprehensive and integrated, addressing energy, economic and social challenges simultaneously. By investing in green infrastructure, stimulating innovation, creating a supportive legislative framework, education and training, sustainable urban development and international collaboration, Europe can achieve its climate neutrality goals and ensure sustainable and equitable economic growth.

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References

1. Abba, Z. Y. I., Balta-Ozkan, N., & Hart, P. (2022). A holistic risk management framework for renewable energy investments. Renewable and Sustainable Energy Reviews, 160, 112305. https://doi.org/https://doi.org/10.1016/j.rser.2022.112305
2. Ahmad, T., Madonski, R., Zhang, D., Huang, C., & Mujeeb, A. (2022). Data-driven probabilistic machine learning in sustainable smart energy/smart energy systems: Key developments, challenges, and future research opportunities in the context of smart grid paradigm. Renewable and Sustainable Energy Reviews, 160, 112128. https://doi.org/https://doi.org/10.1016/j.rser.2022.112128
3. Ahmed, S., Ali, A., Ciocia, A., & D'Angola, A. (2024). Technological Elements behind the Renewable Energy Community: Current Status, Existing Gap, Necessity, and Future Perspective—Overview. In Energies (Vol. 17, Issue 13). https://doi.org/10.3390/en17133100
4. Akaev, A., & Davydova, O. (2023). Climate and Energy: Energy Transition Scenarios and Global Temperature Changes Based on Current Technologies and Trends BT - Reconsidering the Limits to Growth: A Report to the Russian Association of the Club of Rome (V. Sadovnichy, A. Akaev, I. Ilyin, S. Malkov, L. Grinin, & A. Korotayev (eds.); pp. 53–70). Springer International Publishing. https://doi.org/10.1007/978-3-031-34999-7_4
5. Alola, A. A., Adekoya, O. B., & Oliyide, J. A. (2022). Outlook of oil prices and volatility from 1970 to 2040 through global energy mix-security from production to reserves: A nonparametric causality-in-quantiles approach. Resources Policy, 79, 103054. https://doi.org/https://doi.org/10.1016/j.resourpol.2022.103054
6. Androniceanu, A., & Sabie, O. M. (2022). Overview of Green Energy as a Real Strategic Option for Sustainable Development. In Energies (Vol. 15, Issue 22). https://doi.org/10.3390/en15228573
7. Ayesha, Numan, M., Baig, M. F., & Yousif, M. (2023). Reliability evaluation of energy storage systems combined with other grid flexibility options: A review. Journal of Energy Storage, 63, 107022. https://doi.org/https://doi.org/10.1016/j.est.2023.107022
8. Bărbulescu, A., Dumitriu, C. S., & Dragomir, F.-L. (2021). Detecting Aberrant Values and Their Influence on the Time Series Forecast. 2021 International Conference on Electrical, Computer, Communications and Mechatronics Engineering (ICECCME), 1–5. https://doi.org/10.1109/ICECCME52200.2021.9591085
9. Barone, G., Buonomano, A., Forzano, C., Palombo, A., & Russo, G. (2023). The role of energy communities in electricity grid balancing: A flexible tool for smart grid power distribution optimization. Renewable and Sustainable Energy Reviews, 187, 113742. https://doi.org/https://doi.org/10.1016/j.rser.2023.113742
10. Bashir, M. F., Sadiq, M., Talbi, B., Shahzad, L., & Adnan Bashir, M. (2022). An outlook on the development of renewable energy, policy measures to reshape the current energy mix, and how to achieve sustainable economic growth in the post COVID-19 era. Environmental Science and Pollution Research, 29(29), 43636–43647. https://doi.org/10.1007/s11356-022-20010-w
11. Bogdanov, D., Ram, M., Aghahosseini, A., Gulagi, A., Oyewo, A. S., Child, M., Caldera, U., Sadovskaia, K., Farfan, J., De Souza Noel Simas Barbosa, L., Fasihi, M., Khalili, S., Traber, T., & Breyer, C. (2021). Low-cost renewable electricity as the key driver of the global energy transition towards sustainability. Energy, 227, 120467. https://doi.org/https://doi.org/10.1016/j.energy.2021.120467
12. Carfora, A., Pansini, R. V., & Scandurra, G. (2022). Energy dependence, renewable energy generation and import demand: Are EU countries resilient? Renewable Energy, 195, 1262–1274. https://doi.org/https://doi.org/10.1016/j.renene.2022.06.098
13. Chen, L., Hu, Y., Wang, R., Li, X., Chen, Z., Hua, J., Osman, A. I., Farghali, M., Huang, L., Li, J., Dong, L., Rooney, D. W., & Yap, P.-S. (2024). Green building practices to integrate renewable energy in the construction sector: a review. Environmental Chemistry Letters, 22(2), 751–784. https://doi.org/10.1007/s10311-023-01675-2
14. Chen, X. H., Tee, K., Elnahass, M., & Ahmed, R. (2023). Assessing the environmental impacts of renewable energy sources: A case study on air pollution and carbon emissions in China. Journal of Environmental Management, 345, 118525. https://doi.org/https://doi.org/10.1016/j.jenvman.2023.118525
15. Deshmukh, M. K. G., Sameeroddin, M., Abdul, D., & Abdul Sattar, M. (2023). Renewable energy in the 21st century: A review. Materials Today: Proceedings, 80, 1756–1759. https://doi.org/https://doi.org/10.1016/j.matpr.2021.05.501
16. Dumitriu, C. Ş., & Dragomir, F.-L. (2021). Modeling the Signals Collected in Cavitation Field by Stochastic and Artificial Intelligence Methods. 2021 13th International Conference on Electronics, Computers and Artificial Intelligence (ECAI), 1–4. https://doi.org/10.1109/ECAI52376.2021.9515016
17. Eurostat. (2024a). Energy productivity. https://ec.europa.eu/eurostat/databrowser/view/sdg_07_30/default/table?lang=en
18. Eurostat. (2024b). Final energy consumption. https://ec.europa.eu/eurostat/databrowser/view/sdg_07_11/default/table?lang=en&category=sdg.sdg_07
19. Eurostat. (2024c). Net greenhouse gas emissions. https://ec.europa.eu/eurostat/databrowser/view/sdg_13_10/default/table?lang=en
20. Eurostat. (2024d). Real GDP per capita. https://ec.europa.eu/eurostat/databrowser/view/sdg_08_10/default/table?lang=en&category=sdg.sdg_08
21. Eurostat. (2024e). Share of renewable energy in gross final energy consumption by sector. https://ec.europa.eu/eurostat/databrowser/view/sdg_07_40/default/table?lang=en&category=sdg.sdg_07
22. Fu, L., Tu, X., & Liao, J. (2024). Asymmetric impacts of climate policy uncertainty, investor sentiment on energy prices and renewable energy consumption: Evidence from NARDL and wavelet coherence. Journal of Environmental Management, 367, 122057. https://doi.org/https://doi.org/10.1016/j.jenvman.2024.122057
23. Gajdzik, B., Wolniak, R., Nagaj, R., Grebski, W. W., & Romanyshyn, T. (2023). Barriers to Renewable Energy Source (RES) Installations as Determinants of Energy Consumption in EU Countries. In Energies (Vol. 16, Issue 21). https://doi.org/10.3390/en16217364
24. Galimova, T., Ram, M., & Breyer, C. (2022). Mitigation of air pollution and corresponding impacts during a global energy transition towards 100% renewable energy system by 2050. Energy Reports, 8, 14124–14143. https://doi.org/https://doi.org/10.1016/j.egyr.2022.10.343
25. Ghezelbash, A., Khaligh, V., Fahimifard, S. H., & Liu, J. J. (2023). A Comparative Perspective of the Effects of CO2 and Non-CO2 Greenhouse Gas Emissions on Global Solar, Wind, and Geothermal Energy Investment. In Energies (Vol. 16, Issue 7). https://doi.org/10.3390/en16073025
26. Habiba, U., Xinbang, C., & Anwar, A. (2022). Do green technology innovations, financial development, and renewable energy use help to curb carbon emissions? Renewable Energy, 193, 1082–1093. https://doi.org/https://doi.org/10.1016/j.renene.2022.05.084
27. Hassan, Q., Algburi, S., Sameen, A. Z., Salman, H. M., & Jaszczur, M. (2023). A review of hybrid renewable energy systems: Solar and wind-powered solutions: Challenges, opportunities, and policy implications. Results in Engineering, 20, 101621. https://doi.org/https://doi.org/10.1016/j.rineng.2023.101621
28. Hassan, Q., Hsu, C.-Y., MOUNICH, K., Algburi, S., Jaszczur, M., Telba, A. A., Viktor, P., Mahrous Awwad, E., Ahsan, M., Mahmood Ali, B., Khudhair Al-Jiboory, A., Henedy, S. N., Zuhair Sameen, A., & Barakat, M. (2024). Enhancing smart grid integrated renewable distributed generation capacities: Implications for sustainable energy transformation. Sustainable Energy Technologies and Assessments, 66,

103793. https://doi.org/https://doi.org/10.1016/j.seta.2024.103793
29. Hassan, Q., Viktor, P., J. Al-Musawi, T., Mahmood Ali, B., Algburi, S., Alzoubi, H. M., Khudhair Al-Jiboory, A., Zuhair Sameen, A., Salman, H. M., & Jaszczur, M. (2024). The renewable energy role in the global energy Transformations. Renewable Energy Focus, 48, 100545. https://doi.org/https://doi.org/10.1016/j.ref.2024.100545
30. Holechek, J. L., Geli, H. M. E., Sawalhah, M. N., & Valdez, R. (2022). A Global Assessment: Can Renewable Energy Replace Fossil Fuels by 2050? In Sustainability (Vol. 14, Issue 8). https://doi.org/10.3390/su14084792
31. International Renewable Energy Agency. (2021). Net Zero by 2050. https://www.iea.org/reports/net-zero-by-2050
32. Kataray, T., Nitesh, B., Yarram, B., Sinha, S., Cuce, E., Shaik, S., Vigneshwaran, P., & Roy, A. (2023). Integration of smart grid with renewable energy sources: Opportunities and challenges – A comprehensive review. Sustainable Energy Technologies and Assessments, 58, 103363. https://doi.org/https://doi.org/10.1016/j.seta.2023.103363
33. Khalid, M. (2024). Smart grids and renewable energy systems: Perspectives and grid integration challenges. Energy Strategy Reviews, 51, 101299. https://doi.org/https://doi.org/10.1016/j.esr.2024.101299
34. Khan, S. A. R., Godil, D. I., Yu, Z., Abbas, F., & Shamim, M. A. (2022). Adoption of renewable energy sources, low-carbon initiatives, and advanced logistical infrastructure—an step toward integrated global progress. Sustainable Development, 30(1), 275–288. https://doi.org/https://doi.org/10.1002/sd.2243
35. Koengkan, M., Fuinhas, J. A., & Kazemzadeh, E. (2024). Do financial incentive policies for renewable energy development increase the economic growth in Latin American and Caribbean countries? Journal of Sustainable Finance & Investment, 14(1), 161–183. https://doi.org/10.1080/20430795.2022.2031849
36. Kwilinski, A., Lyulyov, O., & Pimonenko, T. (2024). Reducing transport sector CO2 emissions patterns: Environmental technologies and renewable energy. Journal of Open Innovation: Technology, Market, and Complexity, 10(1), 100217. https://doi.org/https://doi.org/10.1016/j.joitmc.2024.100217
37. Kylili, A., Thabit, Q., Nassour, A., & Fokaides, P. A. (2021). Adoption of a holistic framework for innovative sustainable renewable energy development: a case study. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 1–21. https://doi.org/10.1080/15567036.2021.1904058
38. Lu, Y., Khan, Z. A., Alvarez-Alvarado, M. S., Zhang, Y., Huang, Z., & Imran, M. (2020). A Critical Review of Sustainable Energy Policies for the Promotion of Renewable Energy Sources. In Sustainability (Vol. 12, Issue 12). https://doi.org/10.3390/su12125078
39. Luty, L., Zioło, M., Knapik, W., Bąk, I., & Kukuła, K. (2023). Energy Security in Light of Sustainable Development Goals. In Energies (Vol. 16, Issue 3). https://doi.org/10.3390/en16031390
40. Mara, D., Nate, S., Stavytskyy, A., & Kharlamova, G. (2022). The Place of Energy Security in the National Security Framework: An Assessment Approach. In Energies (Vol. 15, Issue 2). https://doi.org/10.3390/en15020658
41. Meng, Z., Sun, H., & Liu, X. (2022). Impact of green fiscal policy on the investment efficiency of renewable energy enterprises in China. Environmental Science and Pollution Research, 29(50), 76216–76234. https://doi.org/10.1007/s11356-022-20832-8
42. Ofremu, G. O., Raimi, B. Y., Yusuf, S. O., Dziwornu, B. A., Nnabuife, S. G., Eze, A. M., & Nnajiofor, C. A. (2024). Exploring the Relationship between Climate Change, Air Pollutants and Human Health: Impacts, Adaptation, and Mitigation Strategies. Green Energy and Resources, 100074. https://doi.org/https://doi.org/10.1016/j.gerr.2024.100074
43. Paraschiv, L. S., & Paraschiv, S. (2023). Contribution of renewable energy (hydro, wind, solar and biomass) to decarbonization and transformation of the electricity generation sector for sustainable development. Energy Reports, 9, 535–544. https://doi.org/https://doi.org/10.1016/j.egyr.2023.07.024
44. Qadir, S. A., Al-Motairi, H., Tahir, F., & Al-Fagih, L. (2021). Incentives and strategies for financing the renewable energy transition: A review. Energy Reports, 7, 3590–3606. https://doi.org/https://doi.org/10.1016/j.egyr.2021.06.041
45. Rahman, Abidur, Farrok, O., & Haque, M. M. (2022). Environmental impact of renewable energy source based electrical power plants: Solar, wind, hydroelectric, biomass, geothermal, tidal, ocean, and osmotic. Renewable and Sustainable Energy Reviews, 161, 112279. https://doi.org/https://doi.org/10.1016/j.rser.2022.112279
46. Rahman, Arifur, Murad, S. M. W., Mohsin, A. K. M., & Wang, X. (2024). Does renewable energy proactively contribute to mitigating carbon emissions in major fossil fuels consuming countries? Journal of Cleaner Production, 452, 142113. https://doi.org/https://doi.org/10.1016/j.jclepro.2024.142113
47. Raihan, A., Begum, R. A., Said, M. N. M., & Pereira, J. J. (2022). Relationship between economic growth, renewable energy use, technological innovation, and carbon emission toward achieving Malaysia's Paris agreement. Environment Systems and Decisions, 42(4), 586–607. https://doi.org/10.1007/s10669-022-09848-0
48. Raihan, A., Muhtasim, D. A., Farhana, S., Pavel, M. I., Faruk, O., Rahman, M., & Mahmood, A. (2022). Nexus between carbon emissions, economic growth, renewable energy use, urbanization, industrialization, technological innovation, and forest area towards achieving environmental sustainability in Bangladesh. Energy and Climate Change, 3, 100080. https://doi.org/https://doi.org/10.1016/j.egycc.2022.100080
49. Rehman, A. ur, Iqbal, S., Shafiq, A., Alshammari, N. F., Dar, S. H., & Iqbal, R. T. (2024). Multifaceted impacts of widespread renewable energy integration on socio-economic, ecological, and regional development. Sustainable Futures, 8, 100241. https://doi.org/https://doi.org/10.1016/j.sftr.2024.100241
50. Seetharaman, Moorthy, K., Patwa, N., Saravanan, & Gupta, Y. (2019). Breaking barriers in deployment of renewable energy. Heliyon, 5(1), e01166. https://doi.org/10.1016/j.heliyon.2019.e01166
51. Shahzad, U., Radulescu, M., Rahim, S., Isik, C., Yousaf, Z., & Ionescu, S. A. (2021). Do Environment-Related Policy Instruments and Technologies Facilitate Renewable Energy Generation? Exploring the Contextual Evidence from Developed Economies. In Energies (Vol. 14, Issue 3). https://doi.org/10.3390/en14030690
52. Su, C.-W., Pang, L.-D., Qin, M., Lobonţ, O.-R., & Umar, M. (2023). The spillover effects among fossil fuel, renewables and carbon markets: Evidence under the dual dilemma of climate change and energy crises. Energy, 274, 127304. https://doi.org/https://doi.org/10.1016/j.energy.2023.127304
53. Tache, F. L. (2010). Trust model for consumer protection (TMCP). 4th International Workshop on Soft Computing Applications, 107–112. https://doi.org/10.1109/SOFA.2010.5565616
54. Tan, K. M., Babu, T. S., Ramachandaramurthy, V. K., Kasinathan, P., Solanki, S. G., & Raveendran, S. K. (2021). Empowering smart grid: A comprehensive review of energy storage technology and application with renewable energy integration. Journal of Energy Storage, 39, 102591. https://doi.org/https://doi.org/10.1016/j.est.2021.102591
55. Wei, X., Mohsin, M., & Zhang, Q. (2022). Role of foreign direct investment and economic growth in renewable energy development. Renewable Energy, 192, 828–837. https://doi.org/https://doi.org/10.1016/j.renene.2022.04.062
56. Wen, J., Okolo, C. V., Ugwuoke, I. C., & Kolani, K. (2022). Research on influencing factors of renewable energy, energy efficiency, on technological innovation. Does trade, investment and human capital development matter? Energy Policy, 160, 112718. https://doi.org/https://doi.org/10.1016/j.enpol.2021.112718
57. Woon, K. S., Phuang, Z. X., Taler, J., Varbanov, P. S., Chong, C. T., Klemeš, J. J., & Lee, C. T. (2023). Recent advances in urban green energy development towards carbon emissions neutrality. Energy, 267, 126502. https://doi.org/https://doi.org/10.1016/j.energy.2022.126502
58. Wu, D., Xie, Y., & Liu, D. (2023). Rethinking the complex effects of the clean energy transition on air pollution abatement: Evidence from

China's coal-to-gas policy. Energy, 283, 128413. https://doi.org/https://doi.org/10.1016/j.energy.2023.128413

59. *Wu, H. (2023). Evaluating the role of renewable energy investment resources and green finance on the economic performance: Evidence from OECD economies. Resources Policy, 80, 103149. https://doi.org/https://doi.org/10.1016/j.resourpol.2022.103149*
60. *Yan, H., Qamruzzaman, M., & Kor, S. (2023). Nexus between Green Investment, Fiscal Policy, Environmental Tax, Energy Price, Natural Resources, and Clean Energy—A Step towards Sustainable Development by Fostering Clean Energy Inclusion. In Sustainability (Vol. 15, Issue 18). https://doi.org/10.3390/su151813591*
61. *Zhang, L., Berk Saydaliev, H., & Ma, X. (2022). Does green finance investment and technological innovation improve renewable energy efficiency and sustainable development goals. Renewable Energy, 193, 991–1000. https://doi.org/https://doi.org/10.1016/j.renene.2022.04.161*
62. *Zhang, W., Yun, X., Meng, W., Xu, H., Zhong, Q., Yu, X., Ren, Y., Shen, H., Chen, Y., Shen, G., Ma, J., Cheng, H., Li, B., Liu, J., Wang, X., & Tao, S. (2021). Urban residential energy switching in China between 1980 and 2014 prevents 2.2 million premature deaths. One Earth, 4(11), 1602–1613. https://doi.org/10.1016/j.oneear.2021.10.013*
63. *Zhang, Y., Han, A., Deng, S., Wang, X., Zhang, H., Hajat, S., Ji, J. S., Liang, W., & Huang, C. (2023). The impact of fossil fuel combustion on children's health and the associated losses of human capital. Global Transitions, 5, 117–124. https://doi.org/https://doi.org/10.1016/j.glt.2023.07.001*
64. *Zhang, Z., Karimi, M. S., Weerasinghe, N. M., Bilan, Y., & Shahzad, U. (2024). Interplay between economic progress, carbon emissions and energy prices on green energy adoption: Evidence from USA and Germany in context of sustainability. Renewable Energy, 232, 121038. https://doi.org/https://doi.org/10.1016/j.renene.2024.121038*
65. *Żuk, P., & Żuk, P. (2024). The role of trust, information and legal stability in the development of renewable energy: the analysis of non-economic factors affecting entrepreneurs' investments in green energy in Poland. Environment, Development and Sustainability, 26(7), 18499–18534. https://doi.org/10.1007/s10668-023-03400-z*