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INTERRELATION OF CARBON NEUTRALITY AND ENVIRONMENTAL REGULATIONS IN EUROPEAN COUNTIES

Serhiy LYEONOV[1*], Yevhen KOVALENKO[2], Inna TIUTIUNYK[3]

[1] Department of Applied Social Science, Silesian University of Technology, Department of Economic cybernetics; serhiy.lyeonov@polsl.pl, ORCID: 0000-0001-5639-3008
Sumy State University, Sumy, Ukraine.
[2] Department of Economics, Entrepreneurship and Business Administration, Sumy State University, Sumy, Ukraine; kovalenko@econ.sumdu.edu.ua, ORCID: 0000-0002-2111-9372
[3] Department of Financial Technologies and Entrepreneurship, Sumy State University, Sumy, Ukraine; i.tiutiunyk@biem.sumdu.edu.ua, ORCID: 0000-0001-5883-2940
* Correspondence author

Purpose: The challenge of achieving carbon neutrality, which involves balancing carbon emissions with their absorption from the atmosphere, remains a central concern for European Union countries. Key goals include improving the effectiveness of environmental regulations and maximizing the use of available energy resources. This study seeks to explore the impact of environmental regulations on a country's progress toward carbon neutrality.
Design/methodology/approach: Various methodologies are employed, including panel stationarity testing, cross-section dependence testing, cointegration analysis, and heterogeneous parameter models. This research using panel data from EU countries spanning from 2000 to 2021, the study develops econometric models to analyse the influence of environmental regulations on the path to carbon neutrality.
Findings: The hypothesis regarding the influence of environmental regulations on carbon neutrality was confirmed for 21 out of the 27 analysed countries.
Practical implications: The results of this research can provide a valuable foundation for guiding EU countries towards carbon neutrality and enhancing governmental strategies to promote low-carbon development.
Originality/value: The findings underscore the necessity of a comprehensive approach to managing a country's energy development, which involves coordinating state actions in enhancing environmental regulation during the transition to low-carbon development.
Keywords: carbon neutrality, low-carbon development, environmental regulations, energy consumption.
Category of the paper: Research paper.

1. Introduction

The Paris Agreement, established in 2015 by nearly 200 nations, stands as a pivotal global accord aimed at combating climate change. The primary objective of this agreement is to maintain the global temperature rise this century well below 2°C above pre-industrial levels, with an aspirational target of limiting the increase to no more than 1.5°C. To achieve this goal, many countries have developed specific emission reduction plans; for instance, the European Union's initiative is known as Fit for 55. Renewable energy technologies such as solar and wind are becoming increasingly efficient and cost-effective, playing a significant role in reducing carbon emissions. The COP26 summit held in Glasgow in 2021 culminated in the Glasgow Climate Pact, which underscores the critical importance of energy efficiency and robust regulatory frameworks.

In 2022, the International Renewable Energy Agency (IRENA) reported a decline in the global weighted average cost of electricity (LCOE) from new utility-scale renewable sources, despite rising material and equipment costs. China made a significant contribution to reducing costs for solar PV and onshore wind, while other regions saw mixed results, with costs increasing in some key markets. IRENA (2023) noted that the global LCOE for new onshore wind projects decreased by 5% from 2021 to 2022, dropping from USD 0.035/kWh to USD 0.033/kWh, and solar PV projects saw a 3% reduction, reaching USD 0.049/kWh. Balcerzak et al. (2024) forecasted a rapid expansion in the renewable energy market, with global renewable energy capacity expected to grow from approximately 1200 GW to nearly 4000 GW by 2023.

Strong environmental regulations are essential for guiding industries towards sustainable practices. A prominent example is the Clean Air Act (CAA) in the United States, first enacted in 1970 and revised in 1990. This comprehensive federal law regulates air pollution from both stationary and mobile sources across the country, demonstrating how stringent environmental laws can drive industries toward sustainability. According to the U.S. Environmental Protection Agency, from 1970 to 2020, the CAA significantly reduced air pollution by 78%, even as the U.S. economy expanded. This reduction includes lower emissions of pollutants such as atmospheric aerosols, airborne particles, sulfur dioxide, nitrogen oxides, volatile organic compounds, carbon monoxide, and lead (EPA, n.d.). Similarly, the European Union's REACH regulation, introduced in 2007, exemplifies how effective environmental laws can encourage industrial sustainability.

Environmental regulations and energy efficiency measures have a substantial impact on consumer behavior and can inform public awareness campaigns. The European Union's Energy Labelling Directive is a case in point, requiring household appliances and other products to display labels indicating their energy efficiency ratings. A 2021 report by the European Commission found that 93% of consumers are aware of the EU energy label, and 79% are influenced by it when making purchasing decisions. This widespread recognition and preference for energy-efficient products, supported by clear and accessible labelling, can shape public awareness and educational campaigns, helping consumers to weigh the pros and cons of choosing energy-efficient products and make informed decisions.

Mukhtarov et al. (2024) analyse the impact of institutional quality on CO2 emissions in Canada from 1996 to 2021, alongside other factors. Their findings indicate that improvements in institutional quality and an increase in renewable energy production and usage significantly contribute to reducing CO2 emissions. The study emphasizes the importance of policies that enhance institutional quality to further decrease emissions. In a related context, Štreimikienė et al. (2024) ranked the 27 EU countries based on their effectiveness in implementing European Green Deal directives and transitioning to eco-friendly technologies as of 2021. Additionally, Mukhtarov et al. (2023) discovered that in Poland, between 1996 and 2021, a higher corruption perception index, as an indicator of institutional quality, has a positive and significant correlation with renewable energy consumption.

Hsu (2024) found a positive correlation between innovation adoption and ESG performance, contributing to sustainable business development in China's electric vehicle industry. Moslehpour et al. (2024) highlighted the critical role of government actions in ensuring effective corporate social responsibility within India's automobile sector. Rajiani (2023) demonstrated that public service motivation, environmental commitment, and organizational citizenship behavior regarding the environment are significant predictors of eco-initiatives among 600 public sector employees in Jakarta, Indonesia. In a study of Urmia, a diverse city in northwest Iran, Khodaparasti and Garabollagh (2023) found that green innovation, environmental ethics, and governance positively impact green public administration. The study also identified strong links between green public administration, green citizenship values, participation in green city initiatives, and social values. It noted that green public administration is a new theoretical approach in governance, not yet fully adopted in Iran, highlighting gaps in theoretical development both globally and nationally.

Balcerzak et al. (2023) explore the key drivers behind the global shift towards sustainable energy and the associated economic challenges. They identify technological advancements, policy frameworks, environmental concerns, and market dynamics as crucial factors. The study discusses the financial costs of new technologies, their effects on traditional energy sectors, and the role of supportive government programs and transnational collaboration. Bucur and Rus (2024) find a general positive correlation between socio-economic development and environmental performance, while also noting exceptions that underscore the importance of successful domestic policies and administration.

Trusina and Jermolajeva (2024) observe that while developed countries have experienced stagnation or decline in energy production in recent years, China has significant potential for renewable energy development, although it has not yet fully realized this potential. Ščurková and Marčanová (2023) examined farmers' awareness of climate change in Slovakia's

Nitra region and their preferred strategies for adaptation and mitigation, aiming to inform climate-focused agricultural policies. Badreddine and Larbi Cherif (2024) attribute the gap between Algeria's stated renewable energy goals and actual progress to a lack of commitment, absence of a cohesive strategy, structural issues such as heavy fossil fuel subsidies, the strong influence of fossil fuel companies, financing difficulties, and monopolistic control over renewable energy initiatives.

Oe et al. (2023) argue that proactive communication of policies and leadership focused on green initiatives are crucial in encouraging local residents to comply with municipal policies, thereby fostering a supportive environment that increases residents' willingness to remain in the area. Du et al. (2024) illustrate the feedback loop between climate change and regional financial budgets, which in turn affects the concentration of the elderly population in those regions.

Fu and Chang (2024) investigate the impact of cross-national and economic sanctions (including those imposed by the United States, European Union, and UN) on green innovations in 130 countries from 1990 to 2020. They find that multilateral sanctions, and those from the USA and EU, significantly hinder environmental management innovations, particularly in areas like air and water pollution control and waste management. However, unilateral and UN sanctions appear to have minimal impact. The negative effects are most pronounced in African countries, though less so in Asian countries. Malý et al. (2023) examine the impact of such sanctions on Czech international commerce and assess the EU's trade policy. Iwu et al. (2023) and Maile & Vyas-Doorgapersad (2023) recommend that developing countries implement economic reforms to stabilize their business environments. Ray (2023) highlights the unpredictability of growth rates among sustainability program beneficiaries, posing challenges for policymakers.

Unlike previous research, this study integrates cross-section dependence testing, heterogeneous parameter models, cointegration testing, and panel stationarity testing, providing a comprehensive evaluation of the relationships between various indicators, including their mutual influences, trend similarities, correlation patterns, and data heterogeneity. The findings of this study can serve as a foundation for guiding EU countries toward carbon neutrality and enhancing governmental tools to support low-carbon development initiatives.

Research on the collective move towards carbon neutrality, driven by environmental regulations, is both timely and vital for crafting a sustainable future. It offers crucial insights for policymakers, businesses, and the public, aiding them in understanding the complexities of attaining carbon neutrality. Emphasizing regulatory frameworks enables the identification of practical solutions and strategies to effectively combat climate change.

Based on these conclusions, the study proposes to test the following hypothesis: Environmental regulations significantly influence carbon neutrality.

2. Methods

This research concentrates on analysing the factors that contribute to achieving carbon neutrality (CN), with a particular emphasis on environmental regulations (ER). The study is focused on EU countries, which were among the pioneers in committing to carbon neutrality at the national level. The analysis covers the period from 2000 to 2021.

According to Caglar and Yavuz (2023) and Niu (2024) the indicator of government spending on environmental protection was chosen as a key indicator of the effectiveness of environmental regulations. This metric evaluates the proportion of government expenditure on environmental protection relative to GDP, data gathered from European Commission (n.d.).

This indicator measures the share of a country's GDP allocated to protecting and improving the environment. Higher government expenditure on environmental protection relative to GDP suggests a stronger commitment to implementing and enforcing environmental regulations. It reflects the extent to which a government prioritizes environmental concerns relative to other policy areas (Kruse et al., 2022).

Financial expenditure is a critical component of turning regulations into actionable programs (Schneider et al., 2010). This indicator highlights the resources available for:

- Pollution control and prevention.
- Conservation of natural resources.
- Development of sustainable energy and infrastructure.

Higher spending often correlates with a more robust capacity to enforce existing regulations and implement new environmental policies.

Governments that enforce stringent environmental regulations typically require greater financial resources to support compliance mechanisms such as:

- Monitoring and enforcement activities.
- Subsidies or incentives for green technologies.
- Public awareness campaigns.

A higher relative expenditure indicates that the government is actively creating and enforcing regulations to protect the environment (Schneider et al., 2010).

While this indicator measures inputs (financial resources), it indirectly reflects the effectiveness of environmental regulations:

- If spending translates to tangible improvements in air and water quality, biodiversity protection, and reduced greenhouse gas emissions, it demonstrates effective regulation.
- Conversely, low expenditure may signal weak enforcement or a lack of regulatory ambition.

Comparing this indicator across countries provides insight into the relative strength of environmental regulations. Nations with higher expenditures relative to GDP are often seen as leaders in environmental governance. This can influence international perceptions of a country's regulatory environment, affecting foreign investments, trade agreements, and participation in global climate initiatives.

European Commission (n.d.) explains methodologies for tracking and comparing environmental expenditures across EU countries and their link to policy implementation.

The dependent variable used to represent carbon neutrality is defined as the ratio of total CO2 emissions produced to the number of emissions that have been mitigated:

$$\boldsymbol{CN} = \frac{\boldsymbol{AE}}{\boldsymbol{CDE+AE}} \tag{1}$$

Here, CN is the country's carbon neutrality; AE is avoided emissions (data gathered from IPCC, n.d.; IEA, 2023); CDE is the volume of CO_2 emissions (data gathered from European Commission (n.d.)).

Carbon Neutrality represents the extent to which a country achieves a balance between emissions produced and avoided emissions. It ranges from 0 to 1, where: (1) CN = 1 implies complete carbon neutrality (all emissions are offset by avoided emissions); (2) CN < 1 implies partial carbon neutrality.

Avoided Emissions are emissions that have been prevented due to specific interventions or actions such as (IPCC, n.d.):

- Renewable energy adoption.
- Energy efficiency improvements.
- Carbon capture and storage technologies.

Governments can use CN to assess the effectiveness of their emissions reduction strategies. It allows comparison of carbon neutrality levels across countries using consistent metrics and useful in tracking progress toward net-zero goals by monitoring the balance between emissions and mitigation efforts.

The influence of environmental regulations on carbon neutrality is assessed through various methods, including panel stationarity tests, cross-section dependence tests, cointegration analysis, and heterogeneous parameter models. The time series data is initially subjected to stationarity testing using methods like the Levin-Lin-Chu test (Levin et al., 2002), the Im–Pesaran–Shin test (Im et al., 2003), and the Augmented Dickey–Fuller test (Cheung, Lai, 1995). Additionally, second-generation tests are employed, such as the Cointegrated Augmented Dickey-Fuller (CADF) test (Pesaran, 2007) and the Break Augmented Cross-Sectionally Augmented Panel Unit-Root Test (BCIPS) statistic (Lee et al., 2013).

Given the significant coherence and policy alignment among EU countries, it is assumed that there is interdependence among individual indicators of ecological development and similarity in their developmental trends. To account for these factors, the second phase of the analysis involves examining cross-section dependence among the indicators. This step is crucial for improving the reliability of the results and avoiding erroneous conclusions. The analysis of cross-sectional dependence utilizes tests such as the Pesaran scaled LM test, Pesaran's test, and the Breusch-Pagan LM test:

$$CD = \sqrt{\frac{2}{N(N-1)}}(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\sqrt{T_{ij}\widehat{\rho_{ij}}} \tag{2}$$

$$\widehat{\rho_{ij}} = \widehat{\rho_{ji}} = \frac{\sum_{t\epsilon T_i\cap Tj}(\widehat{u_{it}}-\overline{\widehat{u_i}})(\widehat{u_{ji}}-\overline{\widehat{u_j}})}{\left\{\sum_{t\epsilon T_i\cap Tj}(\widehat{u_{it}}-\overline{\widehat{u_i}})^2\right\}^{1/2}\left\{\sum_{t\epsilon T_i\cap Tj}(\widehat{u_{ji}}-\overline{\widehat{u_j}})^2\right\}^{1/2}} \tag{3}$$

$$\overline{\widehat{u}_i} = \frac{\sum_{t\epsilon T_i\cap Tj}\widehat{u_{it}}}{\neq(T_i\cap Tj)} \tag{4}$$

Here, N is the size of the sample; T is the time horizon of the analysis; $\widehat{\rho_{ij}}$ represents the sample estimate of the correlation between the residuals, $Tij = \neq (Ti \cap Tj)$ (i.e., the number of common time-series observations between units i and j).

The null hypothesis states that there is no cross-dependence between indicators.

$$LN = T\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\widehat{\rho_{ij}}^2 \tag{5}$$

$$\widehat{\rho_{ij}} = \widehat{\rho_{ji}} = \frac{\sum_{t=1}^{T}\widehat{u_{it}}\widehat{u_{jt}}}{(\sum_{t=1}^{T}\widehat{u_{it}}^2)^{1/2}(\sum_{t=1}^{T}\widehat{u_{jt}}^2)^{1/2}} \tag{6}$$

In the subsequent phase of the research, long-term cointegration among indicators is examined using Westerlund Error Correction Model (ECM) panel cointegration tests:

$$\Delta y_{it} = \delta_i' d_t + \alpha_i y_{i,t-1} + \lambda_i' x_{i,t-1} + \sum_{j=1}^{p_i}\alpha_{ij}\Delta y_{i,t-j} + \sum_{j=-q_i}^{p_i}\gamma_{ij}\Delta x_{i,t-j} + \epsilon_{it} \tag{7}$$

Here, $t = 1, ..., T$ and $i = 1, ..., N$ index the time-series and cross-sectional units, $d_t$contains the fixed components, for which there are three cases: 1) d_t= 0 so has no fixed components; 2) d_t= 1 so Δy_{it} is produced using a constant; 3) d_t = (1, t) so Δy_i is produced using both a constant and a trend.

In the following stage, the parameters of the regression equation that captures the relationship between the indicators are estimated using Feasible Generalized Least Squares (FGLS):

$$\hat{\beta}_{FGLS} = (X'\sum_T^{-1}X)^{-1}X'\ \sum_T^{-1}y \tag{8}$$

3. Results

Following the outlined methodology, the time series data were subjected to stationarity tests (Table 1).

The results from the Levin-Lin-Chu, Im–Pesaran–Shin, and Augmented Dickey-Fuller (ADF) tests, along with second-generation tests such as the Cointegrated Augmented Dickey-Fuller (CADF) and Break Augmented Cross-Sectionally Augmented Panel Unit-Root Test (BCIPS) statistics, summarized in Table 1, confirm the stationarity of the data series. While not all series exhibit stationarity at their original level, their first differences are stationary at a 1% level of statistical significance.

Table 1.
Results of tests for stationarity.

Tests		CN	ER
at level			
Levin-Lin-Chu	Stat.	2.712	-2.997
	Prob.	0.0000	0.0000
Im–Pesaran–Shin	Stat.	1.533	3.488
	Prob.	0.0412	0.0541
ADF	Stat.	-4.134	-4.569
	Prob.	0.0002	0.0001
CADF	Stat.	-1.554	-1.562
	Prob.	0.0425	0.0704
BCIPS	Stat.	-2.501	-5.037
	Prob.	0.0000	0.0000
at the first difference			
Levin-Lin-Chu	Stat.	-5.897	-7.862
	Prob.	0.0000	0.0000
Im–Pesaran–Shin	Stat.	-6.438	-9.445
	Prob.	0.0012	0.0000
ADF	Stat.	-8.989	11.984
	Prob.	0.0002	0.0001
CADF	Stat.	-2.049	-2.516
	Prob.	0.0000	0.0000
BCIPS	Stat.	-9.325	-11.571

Source: author's calculations.

Subsequently, the data series are examined for interdependencies among them (see Table 2).

Table 2.
Cross-Sectional Dependence Tests.

Tests		CN	ER
Breusch-Pagan LM	Stat.	68.683	75.901
	Prob.	0.0000	0.0000
Pesaran scaled LM	Stat.	34.225	53.456
	Prob.	0.0000	0.0000
Pesaran CD	Stat.	104.696	42.609
	Prob.	68.683	75.901

Source: author's calculations.

The findings from the Pesaran scaled LM test, Pesaran test for cross-sectional dependence (CD), and Breusch-Pagan LM tests, as shown in Table 2, indicate significant cross-dependencies among the indicators. In every category, the p-values fall below the critical threshold of 0.005, suggesting that the null hypothesis is rejected, and there is evidence of cross-dependence among indicators within each group. The stationarity of the dataset (Table 1) and the detected cross-dependencies (Table 2) justify the use of Westerlund ECM panel cointegration tests to evaluate cointegration within the data.

Table 3.
Westerlund ECM panel cointegration tests

Tests	Stat.	Prob.	Coeff
Gt	-5.628	0.000	-68.254
Ga	-5.929	0.001	1.324
Pt	-3.878	0.002	-3.654
Pa	-5.825	0.001	-21.325

Note: Gt and Ga are group-mean tests, while Pt and Pa are panel tests. Gt and Ga assess the presence of cointegration in at least one cross-section; Pt and Pa evaluate cointegration across the entire panel.

Source: author's calculations.

Table 4.
Feasible Generalized Least Squares estimation

Country	ER		cons	
	Stat.	Prob.	Stat.	Prob.
Austria	1.215	0.001	1.265	0.045
Belgium	2.490	0.330	0.816	0.120
Bulgaria	6.019	0.000	1.301	0.000
Croatia	6.259	0.000	2.364	0.000
Cyprus	3.383	0.000	4.251	0.000
Czech Republic	1.877	0.011	2.901	0.000
Denmark	5.900	0.678	3.350	0.004
Estonia	2.859	0.000	1.694	0.027
Finland	2.481	0.002	0.089	0.342
France	1.352	0.041	3.732	0.000
Germany	1.817	0.547	3.348	0.072
Greece	3.663	0.029	1.947	0.105
Hungary	4.103	0.036	3.171	0.000
Ireland	0.224	0.022	0.534	0.329
Italy	0.715	0.001	0.776	0.081
Latvia	0.791	0.787	6.584	0.000
Lithuania	1.837	0.528	0.206	0.122
Luxembourg	3.538	0.554	0.758	0.000
Malta	0.333	0.039	5.406	0.201
Netherlands	0.094	0.049	3.766	0.000
Poland	0.857	0.012	5.214	0.000
Portugal	0.620	0.001	6324	0.000
Romania	1.124	0.044	9.289	0.000
Slovak Republic	1.691	0.025	0.547	0.000
Slovenia	0.175	0.024	0.106	0.000
Spain	4.291	0.032	0.916	0.026
Sweden	1.804	0.068	0.565	0.498

Source: author's calculations.

The results from the Westerlund ECM panel cointegration tests, presented in Table 3, confirm the hypothesis of cointegration among the variables. This finding supports the assessment of parameters using the Feasible Generalized Least Squares model, which analyzes the impact of environmental regulations on carbon neutrality in EU countries. The model results also indicate a positive relationship between environmental regulation and carbon neutrality. Specifically, higher government spending on environmental protection leads to a 6.259% increase in carbon neutrality in Croatia, 6.019% in Bulgaria, 4.103% in Hungary, and 4.291% in Spain. These findings support the hypothesis that environmental regulations play a positive role in advancing carbon neutrality. However, the data for Belgium, Denmark, Germany, Latvia, Lithuania, and Sweden do not show statistically significant results.

4. Discussion

Achieving the carbon neutrality targets set by EU countries necessitates a range of measures, including encouraging both the population and businesses to minimize their environmental impact and enhancing the efficiency of energy resource use. This research investigates the effect of environmental regulations on achieving carbon neutrality. Through the application of panel stationarity tests, cross-section dependence tests, cointegration tests, and heterogeneous parameter models, the study confirmed the hypothesis regarding the influence of environmental regulations on carbon neutrality in 21 out of the 27 countries analysed. Increased government expenditure on environmental protection was shown to enhance carbon neutrality, with notable increases of 6.259% in Croatia, 6.019% in Bulgaria, 4.103% in Hungary, and 4.291% in Spain. However, in Belgium, Denmark, Germany, Latvia, Lithuania, and Sweden, the correlation coefficients were not statistically significant.

The comparative analysis of the strength of the connection between indicators reveals that environmental regulations have a more significant impact in countries such as Belgium, Bulgaria, Croatia, Cyprus, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Lithuania, Luxembourg, the Netherlands, the Slovak Republic, Spain, and Sweden.

These findings are consistent with the conclusions of several researchers, including Kuzior et al. (2021), Sotnyk et al. (2022), Sotnyk et al. (2021), Dobrovolska et al. (2024), Katkova et al. (2022), and Streimikis et al. (2020), who emphasize the vital role of environmental regulations in achieving carbon neutrality, energy efficiency, and energy security, even during wartime (Lavreniuk et al., 2023; Tepliuk et al., 2024). The integration of innovative technology, as noted by Kuzior et al. (2022), Kuzior et al. (2023), and Melnyk et al. (2023), along with public investments (Kwilinski et al., 2024) and changes in industrial structure, are essential for attaining carbon neutrality (Vasilyeva et al., 2023; Letunovska et al., 2021). Additionally, improving energy efficiency plays a significant role in reducing CO2 emissions in most countries globally (Wang et al., 2023; Skowron et al., 2023).

Based on these findings, countries where environmental regulations have a more substantial impact should focus on enhancing the quality of state policies and fostering active participation by state institutions in the carbon neutrality process. The results suggest that nations where environmental regulations have a greater influence should prioritize improving policy quality and institutional involvement.

While this study makes practical contributions to the understanding of carbon neutrality, it has several limitations that future research could address. Previous studies, such as those by Wołowiec et al. (2022) and Vasylieva et al. (2020), have identified factors like the quality of the institutional environment, regulatory quality, and corruption control as critical indicators of a country's environmental regulation. These factors, which affect the overall quality of state regulation and the development of corporate social responsibility, should be considered in future research on their impact on carbon neutrality. Additionally, future studies should examine both short-term and long-term relationships between the analysed indicators.

5. Limitations

While this study provides significant insights into the relationship between environmental regulations and progress toward carbon neutrality in European Union countries, several limitations warrant consideration.

1. The study focuses exclusively on EU member states, limiting the generalizability of the results to countries outside this region. Including non-EU nations with diverse regulatory frameworks and economic contexts could provide a more comprehensive understanding of global trends in carbon neutrality.
2. The calculation of carbon neutrality using avoided emissions and CO_2 emissions provides a valuable proxy but may not capture the full complexity of carbon neutrality, which involves broader factors such as methane, nitrous oxide, and other greenhouse gases. While the indicator government expenditure on environmental protection to GDP is a useful proxy, it does not fully capture the complexity of environmental regulations. Some nations may have stringent regulations with low expenditure due to:
   - Efficiency in regulatory frameworks.
   - Greater reliance on private sector compliance.
3. While the study highlights the role of environmental regulations, it does not account for the quality of governance or institutional capacity, which may significantly influence the effectiveness of regulatory measures. Corruption, inefficiencies, or lack of enforcement mechanisms could impact the outcomes of environmental policies. The effectiveness of expenditure depends also on policy design.

Addressing these limitations in future research could enhance the robustness and applicability of findings, contributing to a more nuanced understanding of how environmental regulations shape carbon neutrality trajectories.

6. Conclusion

This study highlights the crucial role of environmental regulations in advancing carbon neutrality among European Union countries. By employing robust econometric methodologies, including panel stationarity testing, cross-section dependence testing, cointegration analysis, and heterogeneous parameter models, the research demonstrates a positive correlation between government expenditures on environmental protection and progress toward carbon neutrality. Specifically, the findings reveal that in 21 out of the 27 countries analysed, increased environmental regulatory efforts significantly enhance carbon neutrality, with notable successes in Croatia, Bulgaria, Hungary, and Spain.

The study underscores the necessity of aligning state policies with business initiatives to ensure a cohesive approach to low-carbon development. The results provide actionable insights for policymakers, suggesting that improving the quality of environmental regulations and fostering institutional involvement can substantially enhance the effectiveness of carbon neutrality initiatives. Furthermore, the inclusion of technological innovation, public investments, and enhanced energy efficiency are identified as complementary strategies to bolster these efforts.

Despite the progress, the findings also reveal disparities among countries where regulatory impacts are statistically insignificant. This indicates the need for further investigation into factors such as institutional quality, regulatory frameworks, and corruption control, which may influence the efficiency of environmental spending and regulations. Future research should explore these dimensions while considering short-term and long-term dynamics to provide a more comprehensive understanding of the pathways to carbon neutrality.

By providing a deeper understanding of the interplay between environmental regulations and carbon neutrality, this study offers valuable guidance for policymakers, businesses, and stakeholders in designing strategies to combat climate change effectively. Aligning environmental, economic, and technological efforts will be essential in fostering a sustainable energy economy and achieving global climate goals.

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