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The Significance of Economic Complexity and Renewable Energy for Decarbonization in Eastern European Countries

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Abstract: Emerging states' path to enhancing the welfare of their citizens has been strongly accompanied by environmental degradation; climate change effects often abrogate their economic results. This zero-sum game must change, and environmental concerns should be considered when the development of a country is discussed and assessed. In this sense, this study's objective is to analyze the impact of economic complexity and renewable energy consumption in the presence of economic growth and urbanization in selected emerging European countries from 1995 to 2021. We used a multiple-methodologic approach to highlight the supportive effects of economic complexity and renewable energy consumption in mitigating carbon emissions. Furthermore, the effects of economic growth and urbanization were emphasized by applying the cointegration regression (CCR), fully modified OLS, and dynamic OLS (FMOLS–DOLS) approaches. Additionally, we used Driscoll–Kraay estimation regression to test the robustness of our results. The results reveal the beneficial role of renewable energy consumption and economic complexity in the decarbonization process of selected countries. Furthermore, the study highlighted the detrimental influence of urbanization and economic growth, which were feasible considering the emerging status of the countries included in the panel.

Keywords: economic complexity; renewable energy; urbanization; environmental degradation

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1. Introduction

1.1. Contextualization

National governments and international bodies struggle to find a compromise between social and economic issues and environmental sustainability [1–3]. Poverty, unemployment, and structural challenges are pushing the budgetary boundaries, challenging national economies and financial systems to address them while fighting against climate change effects [4–10]. Energy transition, greenhouse gas emissions, and biodiversity loss endanger humans' self-existence on Earth, with the vital risk being at the highest level so far in history as we know it [11].

Confronted with climate change pressure, the European Union has driven its targets to mitigate and adapt to climate risks, as stated by the Paris Agreement in 2015. Achieving climate neutrality by 2050 [12] will require a tremendous shift in development to become more sustainable and fairer for all. The European Green Deal highlights the EU strategy for a green and just transition path [13]. Transformations in economies, including industrial and productive structures, are required to organize their potential in a net-zero direction to enhance the economy–environment nexus and impact. An important aspect of this transition is linked to how emerging states and developing nations will be able to increase their resilience and capacity to develop within a framework that focuses on reducing greenhouse gas emissions. The task of cutting emissions by 55% by 2030 [13] will be implemented by

adopting various instruments, such as regulations, climate-friendly innovation adoption, and sustainable finance. The aim of reducing greenhouse gas emissions is being progressively implemented, as seen in Figure 1, which shows the annual decrease in emissions from 1990 to 2022. Still, the EU-27 remains fourth among the top greenhouse gas emitters, according to Climate Watch [14].

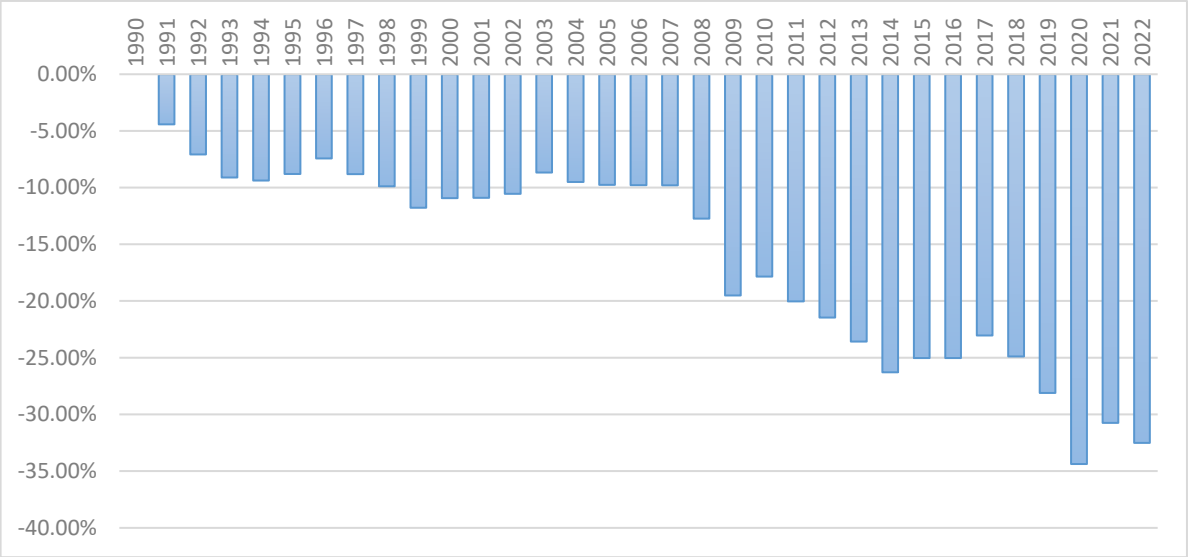


Figure 1. EU−27 total net emissions (UNFCCC) kt CO_2 eq (all greenhouse gases). Scheme 2024. (https://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer (accessed on 7 July 2024)).

All countries must intensify their efforts to diminish their emissions. Moreover, the energy sector is liable for a large share of greenhouse gas emissions (75%, according to [15]). In this sense, one highly appreciated and evaluated driver is renewable energy consumption [16–20]. Additionally, ref. [21] stated that the structure of energy consumption can be optimized by technological innovation. A positive impact of green energy on sustainable development was also found by [22] when they analyzed a panel of 53 emerging economies. Ref. [23] highlighted the relevance of energy resilience policies in the context of geopolitical instability for European Union countries, analyzing the perception of their citizens.

Thus, the European Union's share of renewable energy represents 23% of total consumption (Figure 2), and current targets recognize the need to increase the share of renewables in the mix to 42.5% by 2030.

Moreover, as important as urbanization is considered for the development of states, the more pronounced the adverse effects have become regarding the environmental impact.

The Industrial Revolution is often related to environmental damage, assuming a sudden increase in energy consumption, especially from fossil fuels, and the structural transformations in sectors that became drivers of pollution, including the large-scale use of natural resources. On the other hand, progress has also generated the development of green technologies that are friendly to the environment, contributing to the reduction of pollution, while simultaneously increasing the potential to eliminate or reduce the effects of climate change [24–26].

Additionally, a country's economic complexity describes its capability to produce and transition a complex and diverse range of goods based on its know-how and innovation potential. Economic complexity is a broader indicator of a country's development that requires investments, innovation, knowledge, and skills [27,28]. In this sense, the economic complexity index ranks countries according to their export baskets [29]. A more complex product structure based on knowledge-intensive and technology-intensive processes can determine a robust relationship with the environment [24].

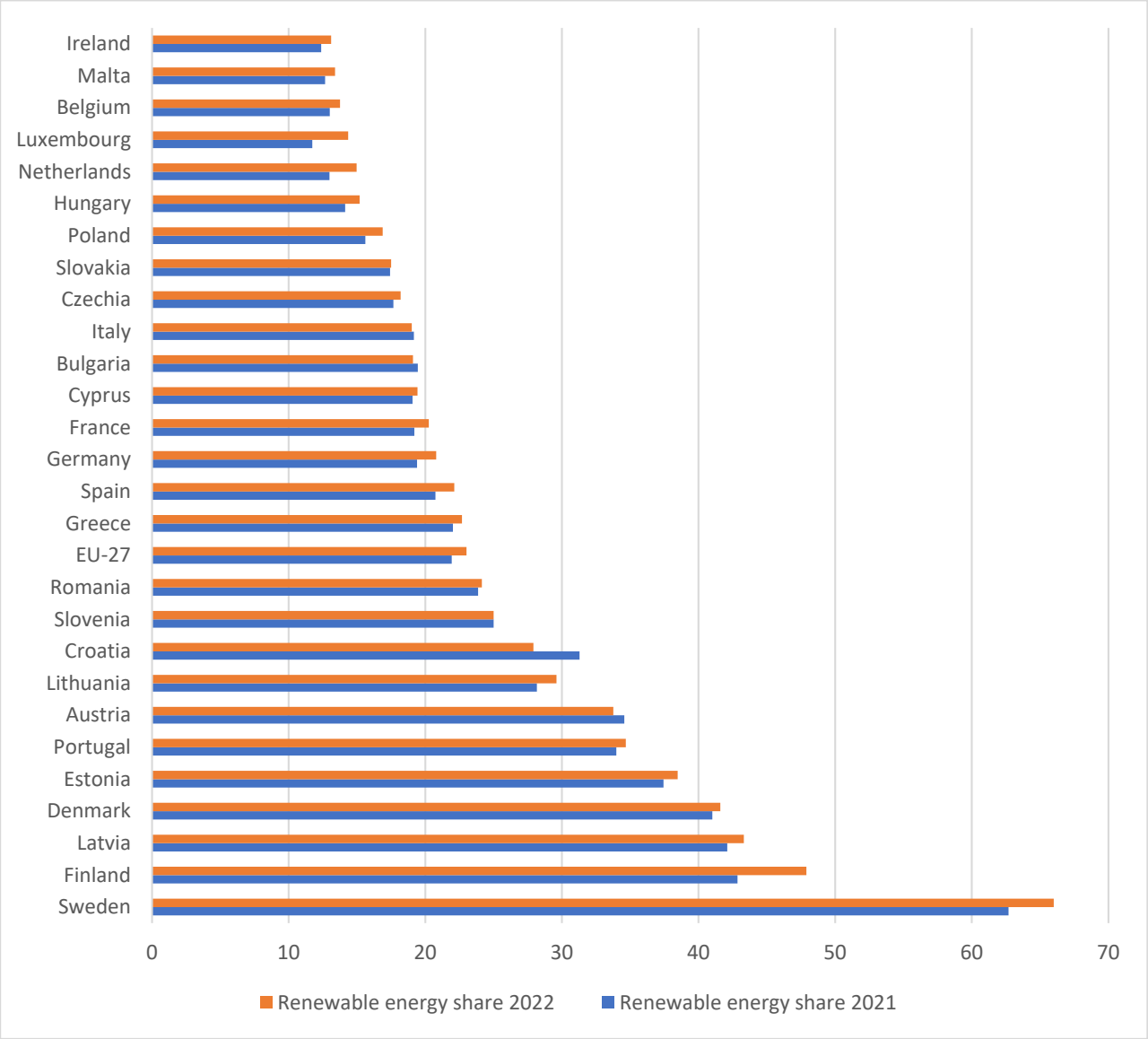


Figure 2. Renewable energy consumption in EU−27, 2021–2022. Source: Eurostat, https://ec.europa.eu/eurostat/databrowser/view/NRG_IND_REN/default/table?lang=en (accessed on 11 July 2024).

Furthermore, Europe's exports are highlighted in Figure 3. The economic complexity of selected European countries is presented in Table 1. When a country's commercial transactions are based on primary commodities and raw materials used as input goods by different buyers, the added value is lower, and the potential to pollute is higher [28]. By contrast, exports based on complex and innovative products are more desirable for rapid and greener development [30].

Though various and valuable, the existing literature often remains trapped in topic-oriented silos. While the literature reflecting renewable energy consumption's impact on environmental quality is quite advanced, the emphasis on economic complexity impact remains limited, especially regarding emerging countries with a former communist background. Consequently, the current paper seeks to contribute to the existing literature in several ways.

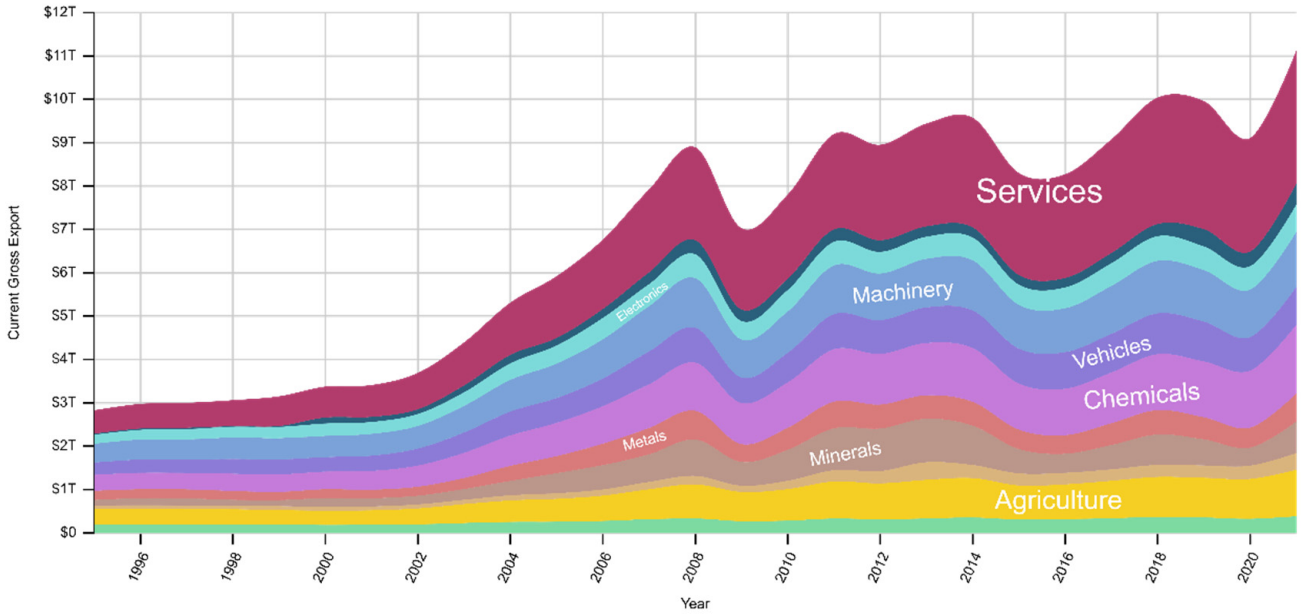


Figure 3. Europe product exports, 1995–2021. Source: downloaded from https://atlas.cid.harvard.edu/explore/stack?country=4&year=2021&queryLevel=group&startYear=1995&productClass=HS&product=undefined&target=Product&partner=undefined (accessed on 11 July 2024).

Table 1. Economic complexity index in selected European countries.

	2021	Position	2020
Bulgaria	0.62	39	0.56
Poland	1.02	25	0.98
Romania	1.23	19	1.22
Hungary	1.52	11	1.52
Czech Republic	1.75	6	1.82

Source: https://atlas.cid.harvard.edu/rankings (accessed on 11 July 2024).

First, based on the above remarks, to fill the literature gap, the purpose of this research is to determine the impact of the independent variables (economic complexity, renewable energy consumption, economic growth, urbanization) on the dependent variable, environmental degradation (measured by carbon emissions), in selected European emerging countries (Bulgaria, Czech Republic, Hungary, Poland, and Romania) from 1995 to 2021. Second, we chose this panel of countries due to their homogeneous aspects reflected by their historical and economic evolution. Thus, the analysis will bring relevant findings and policy directions for the countries' stakeholders to motivate their path to decarbonization and energy transition.

Third, the methodological approach represents another important new element of this study. This research uses three models to test the impact: cointegration regression (CCR), fully modified OLS, and dynamic OLS (FMOLS–DOLS) approaches as primary models. Moreover, we used Driscoll–Kraay estimation regression to test the robustness of the results. By combining multiple modeling methodologies, the relevance of the findings of this study is provided.

1.2. Literature and Research Questions

Moving towards an energy mix dominated by renewable sources is seen as an appropriate option for lowering the ecological footprint and a path towards a healthier ecological environment with fewer emissions [22,31–34]. Reconsidering the energy mix should support a just transition and involve care for social aspects during the process [35], with

renewable energy and clean technologies being essential for diminishing carbon emissions in OECD countries [36].

Ref. [37] proved that excessive natural resource exploitation exacerbates environmental degradation while economic growth targets demand increased energy consumption. Under these circumstances, national governments should target an extended share of renewable energy sources to compensate for the energy demand without increasing environmental degradation. Decision-makers, especially in emerging and developing countries, are reluctant to put growth policies under scrutiny for ecological quality, even if, according to [38], renewable energy consumption reduces air pollution in China in an analysis of China's current five-year plan.

Nevertheless, recent studies have shown that economic growth is not affected by environmentally friendly policies and renewable energy [39]. As the relationship between economic growth and renewable energy expansion is not linear, previous studies concluded that simply expanding the share of such energy sources is insufficient to ensure sustainable growth [40], with efficiency being critical under these circumstances.

A recent paper [31] discovered a reducing effect of renewable energy on carbon emissions in 30 top-emitting countries. Moreover, a positive relationship between economic growth and environmental degradation was found across all quantiles. Similarly, [41] confirms a negative association between renewable energy and carbon emissions, affirming that economic growth creates ecological damage. On the other hand, [42] discovered no causality between carbon emissions and renewable energy, while economic growth increases environmental damage in a selection of emerging economies. Unlike these previous studies, in this research, we added economic complexity besides traditional economic growth to express development rather than simply growth.

The bidirectional causality between renewable energy and non-renewable consumption should also be considered, according to [43], due to lower prices of dirty energy, especially during economic decline.

Ref. [44] studied the specific asymmetries between economic growth and carbon emissions, with numerous policy recommendations for a low-carbon transition.

After confirming the EKC hypothesis, [45] showed that carbon emissions increased in the presence of multiple factors, such as resource abundance, high economic growth, and major direct investment flows, which generate specific attention from decision-makers to find a sustainable path for developing economies by using cleaner technologies.

Ref. [46] examined China's path in the renewable energy era in the context of economic potential maximization, underlining the still important role of fossil fuels and a traditional industrial approach.

A causality analysis revealed the role of renewable energy in enhancing growth through the new jobs that will be created in the context of economic restructuring [47].

Fast-growing developing economies are characterized by increasing urbanization, population density, and standard of living, all contributing to a higher level of environmental degradation [48,49]. Under these circumstances, renewable energy solutions are vital for ensuring future development and improving environmental quality [50].

Analyzing government-driven urbanization in China, [51] found that GDU reduces CO_2 emissions intensity. They revealed the relevance of an urban energy transition, in which urbanization must be approached more rationally. Controlling urban carbon emissions was identified as a key tool in reaching net-zero emissions in China's cities according to [52], especially when the industrial structure lacks upgraded features. Furthermore, [53] evaluated the potential of municipal solid waste as a renewable energy source, thus covering an essential aspect of sustainable development based on circular economy capacity in reducing emissions by adopting innovative waste management strategies.

The effect of economic complexity on environmental quality remains inconclusive in the literature. In this sense, a positive impact has been highlighted by [54], while a negative impact of economic complexity was found by [24,39].

A study on OECD countries from 1998 to 2017 [54] found that economic complexity exerts a mitigation effect on carbon emissions, even if the direct effect on emissions is positive in selected countries. Moreover, when using the Method of Moment Quantile regression, the results found a statistically significant and negative effect of economic complexity on environmental degradation in all quantiles, which adds to the power of ECI in reducing environmental degradation. Furthermore, another study on OECD countries found a positive relationship between ECI and environmental degradation, measured by ecological footprint. However, the harmful effect is discontinued by the human capital index.

An inverted U-shaped curve between economic complexity and environmental degradation was found by [55] in a study covering emerging countries from 1984 to 2017. The results reveal the beneficial effect of higher economic complexity levels on environmental quality. An increase in environmental performance at higher levels of economic complexity was also underlined by [24].

Under these circumstances, this study will consider the following research questions:

- What is the potential of renewable energy consumption in the decarbonization of emerging European countries?
- Will economic complexity be a beneficial factor for environmental quality?
- Will the results of the analysis confirm the detrimental role of urbanization?

2. Data and Methodology

2.1. Data

This study used four independent variables (including control): renewable energy consumption, urbanization, economic growth, and the economic complexity index to test the impact on European carbon emissions. Carbon emissions were used to measure pollution and environmental damage levels in the assessed countries. Renewable energy consumption was chosen as the main indicator of environmentally friendly behavior and is one of the most relevant targets of the European Green Deal for sustainable development. Additionally, a country's innovative and technological development is reflected by its economic complexity level. Furthermore, as the control variable, the study used urbanization (acknowledged in the literature as having an important impact on the environment) and economic growth (appreciated as being directly linked to a state's economic potential). All variables are presented in Table 2. Figure 4 highlights the evolution of analyzed variables over time. It can be observed that the countries included in the panel have comparable evolutions, being a homogeneous group with similar characteristics.

Table 2. Data definitions and data sources.

Variables	Abbrs.	Def.	Sources
Carbon emissions	CO_2	Carbon dioxide emissions stemming from the burning of fossil fuels and the manufacture of cement	OWD [56]
Renewable energy consumption	REN	Renewable energy consumption (% of total final energy consumption)	WBI [57]
Economic complexity index	ECI	Economic complexity index of a country	Harvard's Growth Lab [58]
Urbanization	URB	Urban population	WBI [59]
Economic growth	GDP	GDP per capita (constant 2015 USD)	WBI [60]

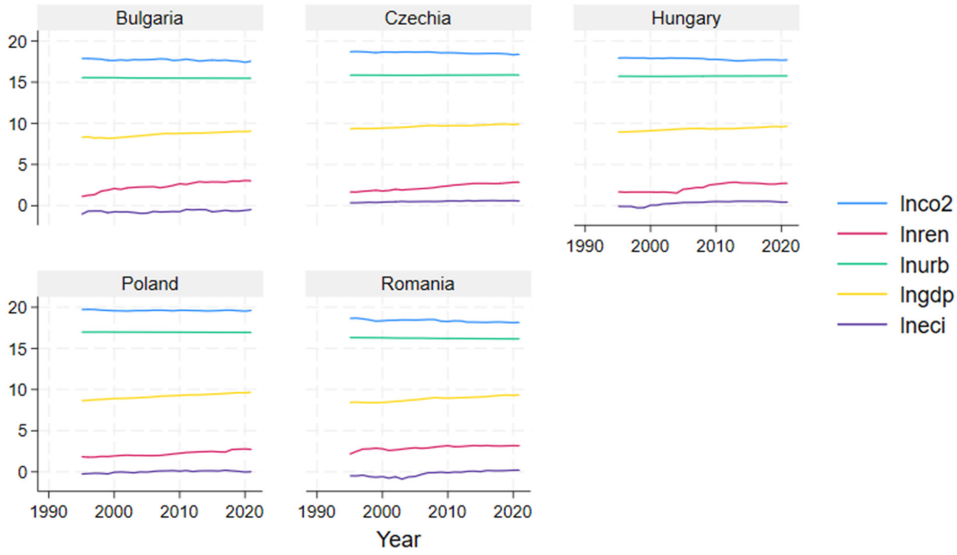


Figure 4. Variables presentation.

2.2. Methodological Approach

The general model is given by the equation below:

$$CO2_{it} = \beta_0 + \beta_1 REN_{it} + \beta_2 URB_{it} + \beta_3 GDP_{it} + \beta_4 ECI_{it} + \varepsilon_{it} \quad (1)$$

We use the cointegration regression (CCR), fully modified OLS, and dynamic OLS (FMOLS–DOLS) approach as the primary models. Moreover, we used Driscoll–Kraay estimation regression to test the robustness of the results. While FMOLS transforms the regressand [61], CCR estimation [62] is based on transforming the regressand and the regressors.

First, we tested the stationarity of the variables included in the model using the Levin–Lin–Chu [63], confirming a cointegration I(1) for all our variables. This test is better for our model specificity, where the panel number and time ratio tend to zero (N < T) by fitting an augmented Dickey–Fuller regression for each panel. The next step was to apply a cointegration test to check for a long-run equilibrium relationship between series.

FM-OLS regression, originally created by [61] and further developed by [64,65], can be presented as follows:

$$Y_{i,t} = \alpha_i + \beta_i X_{i,t} + \varepsilon_{i,t} \quad \forall_t = 1, \ldots, T, \quad i = 1, \ldots, N \quad (2)$$

$Y_{i,t}$ and $X_{i,t}$ are cointegrated with slopes β_i [66].

DOLS introduced by [67,68] was recognized in the literature [69] as being a superior technique in a small sample and can be presented as follows:

$$Y_t = \alpha_i + \beta X'_t + D'_{1t} D' \gamma_1 \sum_{j=-q}^{r} \Delta X'_{t+j} \rho + v_{1,t} \quad (3)$$

Finally, to check the robustness of the model, we applied a nonparametric covariance matrix estimator that produces heteroskedasticity- and autocorrelation-consistent standard errors, named the Driscoll and Kraay estimator [70,71]. Driscoll and Kraay's standard errors of the coefficient estimates represent the square roots of the diagonal elements of the asymptotic (robust) covariance matrix [71].

3. Results and Discussion

3.1. Descriptive Statistics

In Table 3, we present descriptive statistics for all the variables analyzed. Figures 5–8 provide hexagon plots for variable interaction. We can easily observe that carbon emissions have evolved from 36 million to 377 million. Additionally, renewable energy consumption

has increased over the years, and countries have grown from 3% to 24.40%. Moreover, the urban population increased over time by almost five times, while the economic complexity index ranges from 0.35 to 1.84, with a mean of 1.08 over the panel.

Table 3. Descriptive statistics.

Variable	Obs.	Mean	Std Dev	Minimum	Maximum
CO_2	135	128,720,131.00	104,375,068.00	36,533,612.00	377,285,400.00
REN	135	12.31	5.72	3.00	24.40
URB	135	10,871,046.00	6,522,611.00	5,228,804.00	23,842,562.00
GDP	135	10,063.67	418.37	3540.56	20,206.43
ECI	135	1.08	0.46	0.35	1.84

Note: CO_2 = Carbon emissions; REN = Renewable energy consumption; URB = Urbanization; GDP = Economic growth; ECI = Economic complexity index.

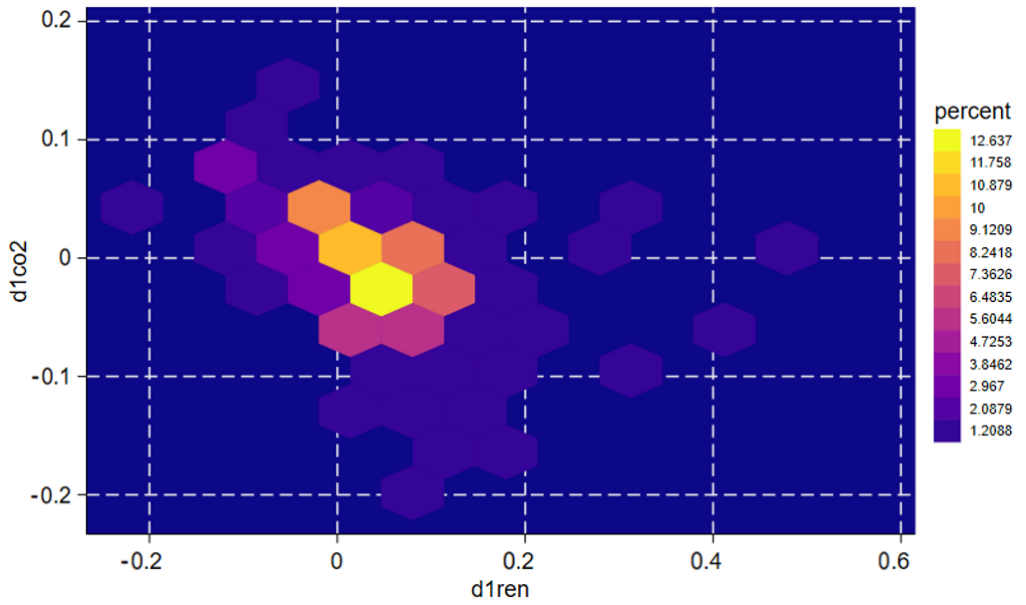


Figure 5. Hexagon plot of REN and CO_2.

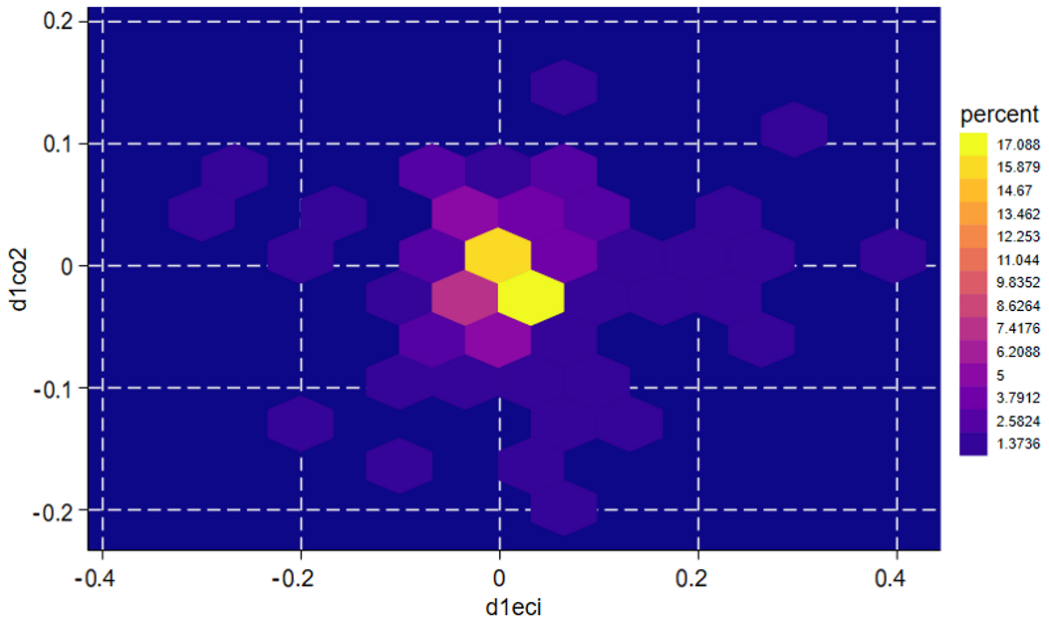


Figure 6. Hexagon plot of REN and ECI.

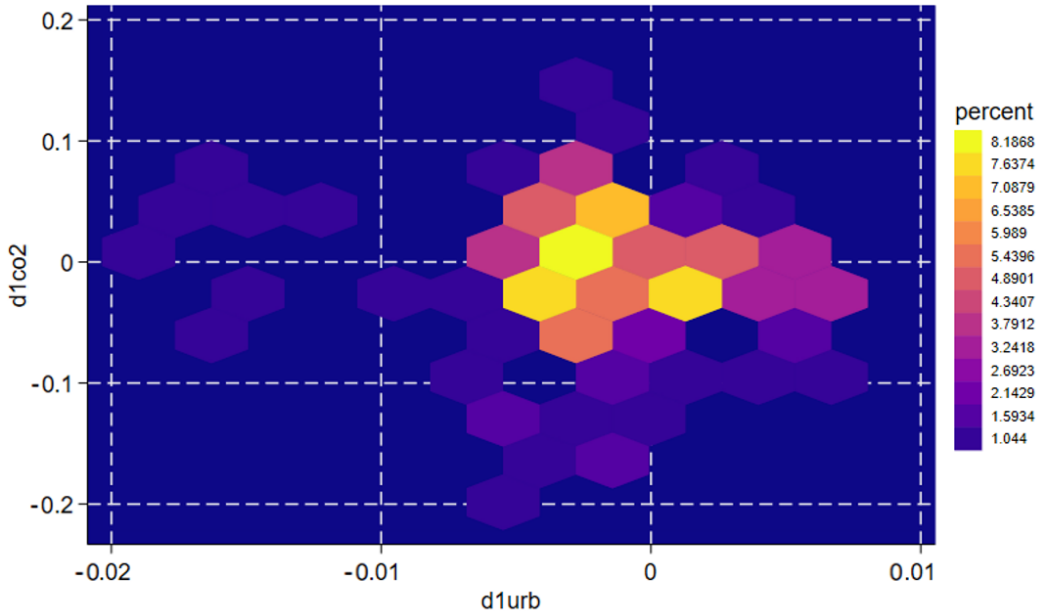


Figure 7. Hexagon plot of REN and URB.

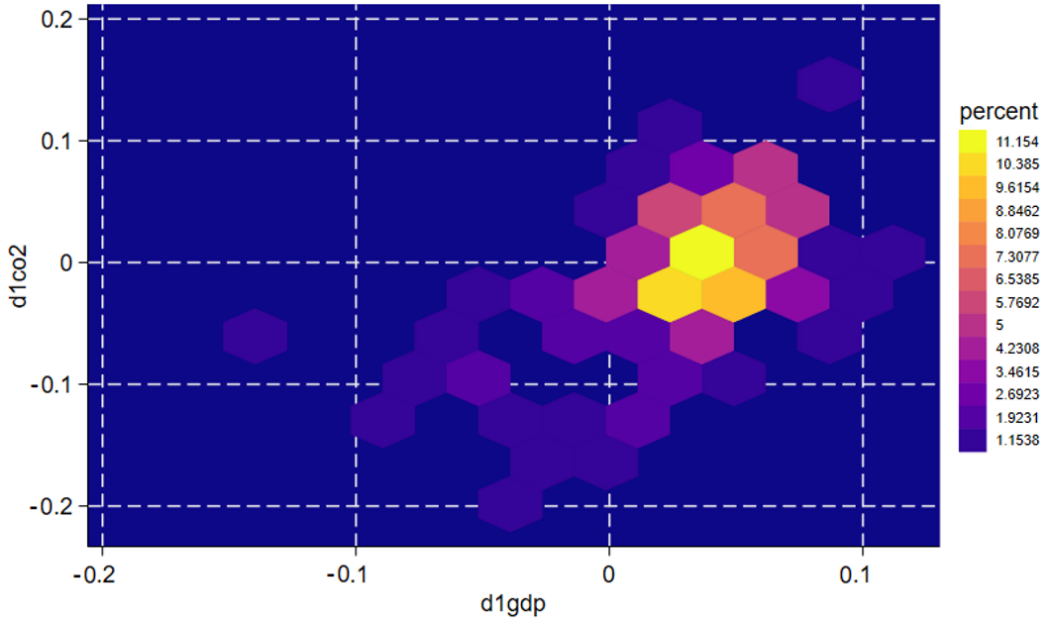


Figure 8. Hexagon plot of REN and GDP.

3.2. Estimations and Discussion

Table 4 presents the evaluation of the stationarity of the variable. It can be observed that, at the level, the variables analyzed were not stationary, but they became stationary after calculating the first difference. Kao test results for cointegration, showing the long-run equilibrium relationship between series, are given in Table 5.

The estimation results presented in Table 6 are obtained by applying three methodologies (CCR, FMOLS, DOLS) to test the impact of renewable energy consumption, urbanization, economic growth, and economic complexity index on carbon emissions.

Table 4. Panel unit root using Levin, Lin and Chu test.

	At Level		At First-Difference	
	Statistic	**Prob.**	**Statistic**	**Prob.**
CO_2	−2.3621	0.0091	−5.4301	0.0000
REN	−1.4938	0.0676	−5.0162	0.0000
URB	−2.0126	0.0221	−2.6920	0.0036
GDP	−0.6961	0.2432	−3.2296	0.0006
ECI	−1.8530	0.0319	−4.0191	0.0000

Note: CO_2 = Carbon emissions; REN = Renewable energy consumption; URB = Urbanization; GDP = Economic growth; ECI = Economic complexity index.

Table 5. Kao test for cointegration.

	Statistic	**Prob.**
Modified Dickey–Fuller t	−3.7190	0.0001
Dickey–Fuller t	−2.6932	0.0035
Augmented Dickey–Fuller t	−3.2065	0.0007
Unadjusted modified Dickey–Fuller t	−3.6983	0.0001
Unadjusted Dickey–Fuller t	−2.6880	0.0036

Table 6. Estimation results.

Variable	**CCR**	**FMOLS**	**DOLS**
REN	−0.4223719 *** (0.0906546)	−0.4269709 *** (3.2980)	−0.3411899 *** (0.107547)
URB	1.225076 *** (0.0833503)	1.224115 *** (0.0836648)	1.235086 *** (0.0792092)
GDP	0.8452406 *** (0.2488771)	0.8392762 *** (0.2403853)	1.183213 *** (0.3340071)
ECI	−0.5634005 *** (0.2234512)	−0.5657797 *** (0.2224739)	−0.832764 *** (0.2873171)
Constant	−7.973767 *** (2.656103)	−7.89175 *** (2.58248)	−11.42552 *** (3.520044)
R^2	0.821	0.818	0.960

Note: REN = Renewable energy consumption; URB = Urbanization; GDP = Economic growth; ECI = Economic complexity index. Standard errors in parentheses; *** $p < 0.01$.

It can be observed that all estimation methods generated statistically significant results with the same impact direction. Another element to note is that the estimations using the DOLS approach were higher than those obtained using the other methodologies, except for renewable energy consumption. From Table 6, several important facts emerge. First, the negative sign of economic complexity in relation to carbon emissions was statistically significant in all approaches, in line with [24,39], but different from [66] findings, which could be explained by the inclusion of additional countries in the panel with lower levels of economic complexity, such as Russia or Turkey. This result underlines the important impact of complex, innovation-driven products developed and commercialized by a country on its sustainable development. High and greener technologies are needed to produce these kinds of products, which positively influence environmental quality.

Further, these results can be linked with the direction of the impact of economic growth (measured by GDP per capita) on carbon emissions, which differs from the ECI sign. This can be explained by the fact that overall economic activity increases CO_2 emissions, and being based on different kinds of technologies, it is not entirely cleaner. Also, economic growth is driven by all sources of economic activities, including industrial and agricultural ones, known as pollution sources, which is in line with [48] results. Stakeholders

should consider these results, as new policies need to be set for development, and structural economic changes should be determined to fit the development path with a more sustainable perspective.

The effect of renewable energy consumption was found to be negative, in line with [30] for Australia and with [40] for emerging countries in Europe and Asia. In this sense, a unit increase in renewable energy reduces carbon emissions by 0.422% (CCR), 0.426% (FMOLS), and 0.341% (DOLS). This can be explained by minimizing pollution levels of energy from solar, wind, water, or other renewable sources. Enlarging the share of renewables in the energy mix will result in lower levels of carbon emissions and an improvement in environmental quality. The alignment of our results with other studies proves that the central point of decarbonization is strongly connected to the intensity of using renewable energy at industrial, firm, and household levels.

Additionally, the urbanization process required by the specific countries analyzed in the panel on their path to development has a positive effect on carbon emissions. Thus, considering our methodologies, a unit increase in URB will lead to an increase of 1.225%, 1.224%, and 1.235% in carbon emissions. According to these three different approaches, these findings are in line with [1,72–74] and can be explained by the process specificity per se. In this sense, a larger number of people will increase the demand for transportation services and employment in different energy-intensive sectors, such as construction, waste generation, and water availability, besides its positive impact (economic growth and development, increased educational opportunities, health services, and other welfare-related features).

The results have significant reverberations from an economic point of view. In this sense, emerging states must adopt a development model based on environmentally friendly technologies while improving the potential of meeting the fundamental needs of their citizens in a "no one being left behind" philosophy. Evolving strongly connected to the energy transition path and net-zero targets, and being aware of the harmful potential of climate change, will increase their resilience and improve their competitive capacity and ability to adapt to future challenges rapidly. Further development and urbanization should be built on greener and smarter strategies; therefore, public transportation optimization, improvements in waste management processes, and reducing fossil fuel-based activities must be considered. As [53] recently highlighted, innovative waste management could diminish environmental damage by using municipal solid waste as a renewable energy source, for example.

The homogeneity of the analyzed countries, all ex-communist states with similar backgrounds and perspectives, enhanced the potential of our study results. Furthermore, their status as European Union countries will properly guide Bulgaria, the Czech Republic, Hungary, Poland, and Romania's path to decarbonization. Specific but commune policies will govern the sustainable development of these countries.

3.3. Robustness Tests

To test the robustness of our analysis, we employed the Driscoll–Kraay estimator, addressing problems related to cross-sectional dependency or heteroscedasticity.

The results shown in Table 7 are in line with the main estimation methods utilized above. Thus, the negative sign of renewable energy consumption and economic complexity was confirmed, as well as the positive signs for urbanization and economic growth. All estimators are statistically significant, with lower levels for estimates in Driscoll–Kraay estimation.

Table 7. Robustness check.

Variable	Driscoll–Kraay
REN	−0.3636167 *** (0.0327409)
URB	1.252701 *** (0.0205278)
GDP	0.6379311 *** (0.1437608)
ECI	−0.3646452 *** (0.0804456)
Constant	−6.666599 *** (1.051817)
R^2	0.932

Note: REN = Renewable energy consumption; URB = Urbanization; GDP = Economic growth; ECI = Economic complexity index. Standard errors in parentheses; *** $p < 0.01$.

4. Conclusions

This study investigated the impact of the economic complexity index on environmental degradation in several emerging European countries during 1995–2021. Additionally, factors such as renewable energy consumption, urbanization, and economic growth have been evaluated as control variables in our models. The study used a triple primary investigation methodology (CCR, FMOLS, DOLS) and a superior results robustness check (Driscoll–Kraay estimator).

The most relevant results of this research highlight the negative sign of ECI and REN in connection with carbon emissions in selected European countries. As such, a higher economic complexity index in these countries has beneficial effects on sustainable development. More innovative, complex, and technology-based products create the context for cleaner development, with less pressure on the environment. This is also correlated with another result related to the estimated sign of renewable energy consumption, which is also found to be negative in relation to environmental degradation. Thus, the ambitious European Commission plans for energy transition are a good tool to increase the usage of renewable energy and limit the pollution generated by producing and using dirty energy. Additionally, energy efficiency increases and interconnected energy systems will become increasingly important for a proper energy transition.

Moreover, the impact of economic growth and urbanization on carbon emissions was found to be harmful. An increase in urbanization is responsible for environmental degradation in selected countries, which is explained by the rapid consumption of resources, the increase in transportation needs, and waste generation. In this sense, local stakeholders must identify methods for diminishing the impact by implementing smart mechanisms for urban transportation, policies and technologies for waste management, and rational strategies for resource usage. Economic growth, the main objective of emerging economies, must be warranted by clean technologies, proper environmental norms, and a more intense understanding among citizens about the importance of their environmental impact.

The conclusions of this study highlight the importance of decoupling nations' growth from fossil fuels and environmentally damaging behaviors. Adopting technology for innovative products with a small ecological footprint and enhancing the usage of renewable energy sources should become the normal for all stakeholders.

This study's limitations and further directions could be considered as follows: while considering CO_2 emissions to capture environmental degradation, a broader variable to be used in future studies could be the ecological footprint, considering various aspects besides carbon emissions. Furthermore, considering a longer period or enlarging the cross-sections could be additionally explored to enhance knowledge in this matter. Also, exploring the impact of different kinds of renewable energy sources could be analyzed in future studies.

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Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

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