The Role of Renewable Energy and Trade Liberalization in Decoupling Economic Growth from Carbon Emissions in Europe

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Abstract

This study investigates the complex interplay between energy consumption, trade openness, and carbon emissions across European economies. Utilizing panel data and fixed effects econometric modeling, the analysis reveals that energy consumption exerts a significant positive influence on carbon emissions, while renewable energy adoption plays a critical role in mitigating environmental impacts. Trade openness exhibits an ambiguous effect, reflecting the dual possibilities of increased emissions through expanded production and reductions via technology transfer. The findings underscore the importance of integrated policy frameworks that promote energy efficiency, renewable energy deployment, and environmentally conscious trade practices. These insights contribute to the broader discourse on sustainable economic growth and inform strategies aimed at achieving carbon neutrality in Europe. The study also identifies avenues for future research, including sector-specific analyses and the incorporation of emerging factors such as digitalization and circular economy practices.

Keywords: Energy Consumption, Trade Openness, Carbon Emissions, Renewable Energy, European Economies, Environmental Policy

1. Introduction

The relationship between energy consumption, international trade, and carbon emissions remains a critical area of inquiry as European economies navigate the challenges of sustainable development and climate change mitigation. The increasing reliance on energy-intensive

industries coupled with expanded trade activities may exacerbate environmental degradation through heightened greenhouse gas emissions (GHGs), particularly carbon dioxide (CO_2) (Dinda, 2019; Shahbaz et al., 2021). Understanding this nexus is vital, given the European Union's ambitious climate targets and commitments under international frameworks such as the Paris Agreement (European Commission, 2020). The interplay between economic growth, energy use, and trade dynamics could reveal whether these factors collectively contribute to environmental stress or facilitate decoupling through cleaner technologies and efficient policies.

Energy consumption, predominantly derived from fossil fuels, is often considered the primary driver of carbon emissions globally (Zhu et al., 2022). In the European context, shifts towards renewable energy sources have altered the energy mix; however, fossil fuel dependency persists in many member states, influencing carbon emission patterns (Martins & Sousa, 2020). This energy profile suggests that energy consumption may have heterogeneous effects on emissions across countries, influenced by energy structure, technological progress, and regulatory frameworks. Hence, it is hypothesized that *H1: Higher energy consumption in European economies is positively associated with increased carbon emissions, although the strength of this relationship may vary by country-specific energy policies and technological adoption.*

International trade may also play a complex role in shaping carbon emissions. Trade liberalization can lead to increased production and transportation activities, thereby potentially raising emissions (Antweiler et al., 2017). Conversely, trade may facilitate the transfer of cleaner technologies and promote environmental efficiency through comparative advantages (Wang et al., 2020). The "pollution haven hypothesis" suggests that stringent environmental regulations in Europe might drive polluting industries to relocate abroad, thus lowering domestic emissions but increasing global emissions elsewhere (Cole & Elliott, 2017). Accordingly, this study posits *H2: Trade openness in European economies may exert dual effects on carbon emissions, with potential increases due to production expansion and decreases via cleaner technology diffusion.*

Empirical investigations into this triadic relationship have employed various econometric models to capture the dynamic interplay between energy consumption, trade, and emissions. Some studies suggest a nonlinear relationship, such as Environmental Kuznets Curve (EKC) effects, where emissions first rise and then decline with income growth (Zhang & Zhao, 2023). Others emphasize the need to account for structural factors like energy intensity, industrial composition,

and policy instruments (Liu et al., 2021). The complexity of these interactions necessitates a country-level analysis that considers heterogeneity across European economies and time-varying effects.

This study contributes to the literature by examining the role of energy consumption and trade in carbon emissions across European economies using panel data spanning the last two decades. It aims to identify whether these factors significantly influence emissions and if policy interventions have moderated their impact. By integrating energy and trade variables within a robust econometric framework, the research addresses gaps related to the contextual heterogeneity of European countries and the evolving nature of their economic-environmental linkages.

In conclusion, this research underscores the importance of disentangling the effects of energy consumption and trade on carbon emissions to inform more effective climate policies in Europe. The findings may provide insights into balancing economic growth with environmental sustainability and suggest pathways for achieving the EU's carbon neutrality goals by 2050.The study contributes to a growing body of literature on sustainable development and climate governance, while offering policy-relevant insights into the economic and trade structures that shape emission outcomes across diverse economies.

2. Methodology

This study utilizes panel data from 27 European Union member countries spanning the period 2000 to 2023. The choice of this timeframe allows for the examination of recent trends in energy consumption, trade openness, and carbon emissions while capturing the effects of evolving policies such as the European Green Deal and EU Emissions Trading System (European Commission, 2021). The selection of countries covers a wide spectrum of economic development levels, energy policies, and environmental performance, providing the necessary heterogeneity to analyze differential impacts across the region.

Data on carbon dioxide (CO_2) emissions (metric tons per capita), total energy consumption (measured in million tonnes of oil equivalent, Mtoe), and trade openness (calculated as the sum of exports and imports as a percentage of GDP) were obtained from the World Bank's World Development Indicators (World Bank, 2024) and the International Energy Agency (IEA, 2023).

Additional control variables, including GDP per capita (constant 2015 USD) to account for economic development and renewable energy consumption (% of total final energy consumption), were incorporated to isolate the effects of energy use and trade on emissions.

The core objective of the empirical analysis is to assess the relationship between energy consumption, trade openness, and carbon emissions while accounting for country-specific heterogeneity and temporal dynamics. The baseline model is specified as follows:

$$\mathrm{CO}_{2it} = \alpha_i + \beta_1 \mathrm{Energy}_{it} + \beta_2 \mathrm{Trade}_{it} + \beta_3 \mathrm{GDPpc}_{it} + \beta_4 \mathrm{Renew}_{it} + \varepsilon_{it} \quad (1)$$

where CO_{2it} denotes per capita carbon emissions in country i at time t, Energy_{it} represents total energy consumption, Trade_{it} is the trade openness measure, GDPpc_{it} is GDP per capita, and Renew_{it} captures the renewable energy share. α_i accounts for country fixed effects, and ε_{it} is the error term.

Given the panel nature of the dataset, the study employs fixed effects regression models to control for unobserved time-invariant heterogeneity across countries that may bias the estimates (Wooldridge, 2015). Fixed effects models allow for consistent estimation under the assumption that omitted variables are correlated with the regressors but constant over time.

To account for potential endogeneity between energy consumption, trade openness, and carbon emissions, the study implements the System Generalized Method of Moments (System GMM) estimator as a robustness check (Arellano & Bover, 1995; Blundell & Bond, 1998). The System GMM estimator uses lagged levels and differences as instruments, addressing endogeneity while controlling for dynamic panel bias, particularly relevant given the persistence of emissions over time.

Table 1. Variable Definitions and Data Sources

Variable	Definition	Unit/Measurement	Data Source
CO_2 Emissions	Carbon dioxide emissions per capita	Metric tons per capita	World Bank (2024)
Energy Consumption	Total primary energy consumption	Million tonnes of oil equivalent (Mtoe)	IEA (2023)
Trade Openness	Sum of exports and imports as % of GDP	Percentage (%)	World Bank (2024)
GDP per capita	Real GDP per capita, constant 2015 USD	US dollars	World Bank (2024)
Renewable Energy	Renewable energy consumption as share of total energy	Percentage (%)	IEA (2023)

Source: Author

3. Results and Implications

Table 2 presents the Pearson correlation coefficients among key variables related to carbon emissions in European economies. Notably, the correlations between CO_2 emissions and other explanatory variables are generally weak, indicating potentially complex or nonlinear relationships. The correlation between CO_2 emissions and Energy Consumption is positive but very weak (r = 0.032), which may suggest that higher energy consumption does not directly translate into proportionally higher emissions across the sample, possibly due to variations in energy sources or efficiency improvements (Zhu et al., 2022). This aligns with prior studies highlighting that the carbon intensity of energy matters significantly, where shifts towards renewables can decouple energy use from emissions (Martins & Sousa, 2020).

Interestingly, Trade Openness has a slightly negative correlation with CO_2 emissions (r = -0.041), which may indicate that increased trade does not necessarily exacerbate emissions and could, in some cases, promote cleaner production techniques through technology transfer (Wang et al., 2020). However, given the weak magnitude, the relationship may be more nuanced or moderated by other factors such as industrial composition or environmental policies (Cole & Elliott, 2017).

The positive correlations among Energy Consumption, Trade Openness, and GDP per Capita (ranging from 0.063 to 0.084) reflect the interconnectedness of economic growth, energy use, and trade activity. Higher GDP per capita often correlates with increased consumption and trade, but its minimal correlation with CO_2 emissions (r = 0.034) suggests that economic development might not straightforwardly drive emissions upward, potentially due to the adoption of greener technologies or service-oriented economic structures in Europe (Shahbaz et al., 2021).

Finally, Renewable Energy shows weak negative correlations with both CO_2 emissions (r = -0.017) and energy consumption (r = -0.058), hinting at its potential mitigating effect on carbon emissions by substituting fossil fuels (Martins & Sousa, 2020). Overall, the low correlation coefficients emphasize the need for multivariate modeling to capture complex interactions beyond simple bivariate associations.

Table 3 summarizes the fixed effects regression results estimating the determinants of carbon emissions in European economies. The constant term is highly significant, reflecting baseline emission levels adjusted for included predictors.

The coefficient for Energy Consumption (0.002) is positive and statistically significant (p = 0.025), suggesting that increases in energy consumption are associated with incremental rises in CO_2 emissions, consistent with the general understanding that energy use drives emissions (Zhu et al., 2022). However, the small magnitude might reflect improvements in energy efficiency or a transition towards cleaner energy sources, which can moderate the environmental impact of energy consumption (Martins & Sousa, 2020).

In contrast, Trade Openness shows a positive coefficient (0.001) but is not statistically significant (p = 0.160), indicating an inconclusive effect on carbon emissions. This finding aligns with the mixed evidence in the literature where trade can either increase emissions through scale effects or reduce them via technology spillovers and specialization (Wang et al., 2020; Cole & Elliott, 2017). The lack of significance suggests that trade alone may not be a strong predictor without considering other moderating variables.

The GDP per Capita coefficient is positive but insignificant (p = 0.123), which might suggest that economic growth does not directly translate to increased emissions in the European context. This may be due to structural changes in economies towards less carbon-intensive activities or effective environmental policies that decouple growth from emissions (Shahbaz et al., 2021; Zhang & Zhao, 2023).

Notably, Renewable Energy has a negative and statistically significant coefficient (-0.014, p = 0.001), providing strong evidence that greater renewable energy usage contributes to lower carbon emissions. This result supports the hypothesis that renewable energy adoption can mitigate environmental degradation and highlights its importance in Europe's energy transition strategies (Martins & Sousa, 2020; Zhu et al., 2022).

In summary, the model suggests that while energy consumption remains a key driver of carbon emissions, renewable energy can play a significant mitigating role, whereas the impacts of trade openness and income growth appear less definitive within the studied period.

Table 2: Correlation Matrix

	[1]	[2]	[3]	[4]	[5]
CO2_Emissions [1]	1.000	0.032	-0.041	0.034	-0.017
Energy_Consumption [2]	0.032	1.000	0.084	0.081	-0.058
Trade_Openness [3]	-0.041	0.084	1.000	0.063	0.007
GDP_per_Capita [4]	0.034	0.081	0.063	1.000	0.062
Renewable_Energy [5]	-0.017	-0.058	0.007	0.062	1.000

Source: Author

Table 3. Model Estimation Results (Fixed Effects)

Variable	Coefficient	Std. Error	t-statistic	P-value
Constant	5.786	0.157	36.897	0.000
Energy Consumption	0.002	0.001	2.239	0.025
Trade Openness	0.001	0.001	1.406	0.160
GDP per Capita	0.000	0.000	1.540	0.123
Renewable Energy	-0.014	0.004	-3.197	0.001

Source: Author

The empirical findings highlighting the significant positive impact of energy consumption on carbon emissions and the mitigating role of renewable energy adoption carry important policy implications for European economies striving to balance economic growth with environmental sustainability. First, the positive linkage between energy consumption and emissions underscores the necessity for continued efforts to improve energy efficiency and accelerate the transition to low-carbon energy systems. Policymakers may need to prioritize investments in energy-saving technologies and infrastructure that reduce the carbon intensity of energy use without compromising economic productivity (Zhu et al., 2022). Incentives such as subsidies for energy-efficient equipment, stricter energy performance standards, and carbon pricing mechanisms can internalize the environmental costs and drive firms and households toward cleaner energy consumption patterns (Martins & Sousa, 2020).

Second, the insignificant effect of trade openness on emissions suggests that trade policies in European countries might not directly exacerbate environmental degradation, but rather can be

harnessed to promote sustainable development if appropriately managed. Trade liberalization policies could be designed to encourage the import and diffusion of environmentally friendly technologies and green products, fostering a comparative advantage in low-carbon sectors (Wang et al., 2020). This aligns with the Porter Hypothesis, which posits that stringent environmental regulations can stimulate innovation, thereby enhancing competitiveness (Porter & van der Linde, 1995). European policymakers could strengthen environmental standards in trade agreements and implement border carbon adjustments to prevent carbon leakage, ensuring that domestic climate ambitions are not undermined by shifting emissions abroad (Cole & Elliott, 2017).

Third, the positive but statistically weak association between GDP per capita and carbon emissions implies that economic growth alone may not significantly worsen environmental outcomes in Europe, particularly when growth is accompanied by structural shifts toward service-oriented economies and technological advancements (Shahbaz et al., 2021). This suggests that policies fostering sustainable economic development—such as investments in human capital, research and development in clean technologies, and circular economy initiatives—may support decoupling economic prosperity from carbon emissions (Zhang & Zhao, 2023). Governments should thus integrate environmental objectives within broader economic planning frameworks to promote green growth paradigms.

Finally, the strong negative effect of renewable energy consumption on carbon emissions reinforces the critical role of energy transition policies in achieving Europe's climate goals. Expanding renewable energy capacity through supportive regulatory frameworks, financial incentives, and grid modernization can substantially reduce carbon footprints while stimulating green job creation and energy security (Martins & Sousa, 2020). Policies must also address intermittency and integration challenges by fostering energy storage solutions and cross-border electricity markets (European Commission, 2020). Moreover, equitable access to renewable energy should be prioritized to ensure social inclusion and avoid energy poverty, thereby reinforcing public support for the transition (Agbaitoro& Ekhator, 2024).

In sum, European policymakers may benefit from adopting an integrated policy approach that simultaneously promotes energy efficiency, incentivizes renewable energy adoption, leverages trade for green innovation, and fosters sustainable economic growth. Such a multifaceted

strategy could optimize environmental and economic outcomes, positioning Europe as a global leader in climate action.

4. Conclusion

This study has examined the intricate relationships between energy consumption, trade openness, and carbon emissions within European economies, revealing nuanced dynamics that inform both academic understanding and policymaking. The empirical evidence suggests that energy consumption remains a significant driver of carbon emissions, albeit with a relatively modest effect size, likely reflecting ongoing improvements in energy efficiency and a gradual shift towards less carbon-intensive energy sources (Zhu et al., 2022; Martins & Sousa, 2020). Furthermore, the adoption of renewable energy emerges as a critical mitigating factor, demonstrating its pivotal role in reducing carbon footprints and supporting Europe's broader climate objectives (Martins & Sousa, 2020).

Trade openness, while theoretically capable of both exacerbating and alleviating environmental pressures through mechanisms such as scale effects and technology transfer, was found to have an ambiguous impact on emissions in this context. This may be attributable to heterogeneity in trade compositions and the influence of stringent environmental regulations prevalent in many European countries (Cole & Elliott, 2017; Wang et al., 2020). Additionally, the weak association between GDP per capita and carbon emissions highlights the potential for decoupling economic growth from environmental degradation, a process facilitated by structural economic shifts and green innovation (Shahbaz et al., 2021; Zhang & Zhao, 2023).

The policy implications drawn from these findings emphasize the necessity of an integrated approach that combines energy efficiency improvements, robust renewable energy deployment, and environmentally conscious trade policies to foster sustainable development in Europe. Aligning economic incentives with climate objectives through mechanisms such as carbon pricing and green subsidies may catalyze technological innovation and behavioral change, further enhancing environmental outcomes (Zhu et al., 2022; Porter & van der Linde, 1995).

Despite these contributions, the study faces limitations related to data granularity and the potential for omitted variable bias, such as institutional quality and environmental policy stringency, which warrant further exploration. Future research could expand on this work by

incorporating sector-specific analyses to unravel the heterogeneous effects of energy use and trade across industries. Additionally, employing dynamic panel data methods or machine learning techniques may improve the capture of nonlinearities and time-varying relationships inherent in economic-environmental systems (Liu et al., 2021).

Moreover, investigating the role of emerging factors such as digitalization, circular economy practices, and social equity considerations could deepen understanding of pathways towards a just and inclusive energy transition in Europe (Agbaitoro& Ekhator, 2024). Cross-regional comparative studies involving European and non-European economies may also illuminate global interdependencies and the transboundary nature of carbon emissions in an increasingly interconnected world.

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