INTEGRATED APPROACHES TO CLIMATE POLICY: EVALUATING ENERGY CONSUMPTION, TRADE DYNAMICS, AND CARBON EMISSION REDUCTION STRATEGIES IN EUROPEAN COUNTRIES

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DOI: https://doi.org/10.64633/wissj.v9i6.30

Keywords

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

Abstract

This paper examines the complex interlinkages of energy use, trade openness, and carbon emissions in European economies from 2015 t02023. By employing panel data econometric techniques, like fixed and interaction terms, it is observed that higher energy use inclines toward higher levels of carbon emissions, although it is significantly moderated by the share of the renewable component in the energy mix. Trade openness plays a dual role, possibly transferring a surge in emissions through increased production while enabling cleaner technology transfers. Sensitivity checks indicate that interlinkages vary among countries experiencing varying levels of incomes and regimes for environmental policy. The findings emphasize the importance of aligning environment-friendly trade regulations and renewable energy policies for sustainable growth and carbon control objectives. Policy suggestions emphasize country-specific approaches, higher investments in renewables, and trade agreements that introduce environmental standards. The paper contributes toward the growing line of research into energy-environment-trade nexus and provides results that are valuable for policy designers aiming toward balancing ecological and growth objectives for the Europe region.

1. Introduction

The nexus between energy consumption-international trade and carbon emissions has come out as a prominent priority focus within environmental and economics research, particularly for the economies of Europe. Given that there is a necessity for nations to align economic growth and sustainability goals, understanding the interdynamic nexus between the variables may yield some useful pointers for policy choice-makers seeking a mitigation of climate change impacts (Zhu et al., 2022). The European Union (EU), characterized by its ambitious climate policies and commitment to carbon neutrality by 2050, provides a useful case for considering how energy consumption and trade flow patterns potentially influence carbon emission trajectories (European Commission, 2021).

Energy use is a main impetus to economic growth yet often has a very high environmental price tag. Energy use based on fossil fuels for most Western and Northern European countries creates carbon dioxide (CO_2) emissions that are closely linked to global warming (Wang et al., 2023). The transition of the energy sector towards cleaner energy and increased energy intensity measures has a potential disassociation of environmental damage from economic growth, although this linkage is non-uniform or linear for each of the many different European economies (Khan et al., 2021). Furthermore, the makeup of energy use whether coal- or gas-centered or based mainly on clean sources of energy has a vast bearing on the amount of emissions and thus the environmental intensity of growth.

Trade can be a transmission vector either for positive or negative environmental outcomes. While trade openness can incentivize production and energy use and therefore increase carbon levels through scale effects (Zhao & Yang, 2020), trade provides a conduit for the transfer of green technologies and cleaner production practices that can yield decreases in emissions through technological and compositional effects (Lee et al., 2022). To comprehensively account for the complex trade flow and energy consumption interdependencies, empirical examination needs to be sensitive and detailed, particularly for the case of Europe, in which trade intensity and energy regimes significantly diverge among states.

Some recent studies have used econometric models for examining such linkages, often finding that while energy use has a tendency to amplify carbon intensity, trade openness has a mixed or conditional influence depending upon country-specific stages of development and energy mix (Nguyen et al., 2024). While those advanced economies that possess well-built infrastructures for clean energy are capable of experiencing trade-driven spillovers in technology that reduce their carbon intensity, for instance, fossil fuel-based economies can experience trade-driven increases in their own emissions (Petrović et al., 2023). These differential results give a rationale for country-specific research that should be undertaken in the broader European perspective.

In addition, the effect of policy frameworks cannot be underrated. Europe's environmental regulations, carbon pricing instruments, and international agreement engagements like the Paris Accord frame firms' and governments' energy and trade decisions based on incentive and constraint conditions (European Environment Agency, 2023). The interaction between regulatory policy and market forces, thus, represents a main component that can intervene into energy consumption and trade and their effect on carbon emissions. Exploring the energy consumption-trade-carbon nexus for the economies of Europe offers one of the potential avenues for understanding the interlinks for sustainable development.

2. Literature

2.2. Empirical Review

The interlinkage between energy consumption, foreign trade, and carbon emissions in the Europe economies has been examined comprehensively in empirical literature. Extensive literature posits energy consumption, and more particularly fossil fuel consumption, as the prime factor attributing to carbon emissions. Akadiri et al. (2025), employing a Panel Vector Autoregressive (PVAR) model, report a significant positive effect of fossil fuel consumption on CO_2 emissions and a weaker negative effect of renewable energy consumption. This finding identifies a necessity for a transition from fossil fuels and increasing an emphasis toward employing a means of curtailment through shifting sources. The European Union

Emissions Trading System (EU ETS) has also come into focus for examination in its role in curbing emissions. A counterfactual analysis by academicians (2024), employing matrix completion and fixed effects estimation, reports that EU ETS resulted in a curtailment of CO_2 by a figure of 15.4% from sectors selected between the years 2005 and 2020. This reflects the efficacy of market instruments in ensuring the curtailment of emissions.

Trade openness has also become a factor that defines carbon emissions. Lee et al. (2022) suggest that trade openness can promote production and energy use and thus increase carbon emissions through the influence of scales. Trade can also support the diffusion of green technologies and cleaner production methods and lead to a decline in emissions through the influence of technology and composition.

Another focus has been the energy-emission nexus and the contribution of growth in the economy. Petrović et al. (2023) maintains that while growth in the economy can translate into increased energy consumption and pollution, adopting energy-efficient technologies and clean energy sources breaks this association and promotes sustainable growth. Petrović et al. (2023) suggest that increased investments in clean energy and energy efficiency can reduce CO_2 pollution while simultaneously securing economic growth.

Empirical evidence also demonstrates that sectoral energy consumption structure plays a significant role in determining carbon emission outcomes in European countries. Industrial sectors, whose energy use is typically enormous, normally constitute prime sources of carbon emissions, particularly when fossil fuels predominate in energy structure (Apergis & Payne, 2016; Iqbal et al., 2022).

In trade openness, more studies have observed the important role of international cooperation and technological spillovers in shaping environmental outcomes. For example, Zhu et al. (2022) derive that more-integrated countries into regional and global value chains exhibit higher levels of diffusion for clean technologies that achieve lower carbon intensity amid swelling trade volumes. The effect might be particularly prominent in the European Union due to its relatively high environmental protection and a common climate policy that incentivizes the exploitation of greener technologies through trade linkages (European Environment Agency, 2023). In any event, the environmental benefits of trade openness would need the absorptive capacity of economies for adopting and exploiting the technologies effectively (Lee et al., 2022).

Studies employing autoregressive distributed lag and error correction models routinely report that in the short run, trade openness and energy consumption tend to increase emissions due to adjustment costs and lagged responses of policy (Nguyen et al., 2024; Wang et al., 2023). In the long run, yet, renewable energy infrastructure and technology diffusion through trade can lead to a decline in emissions characteristic of a dynamic and evolving association. The findings suggest that there is a need for long-term planning and continuous policy adjustment for Europe in order for it to enjoy potential benefits of trade and energy transition for climate mitigation.

2.2. Hypotheses Development

Energy consumption has long been found as a main driver of carbon emissions globally, and those of Europe are no exception. Different empirical estimations affirm the positive association between total energy consumption and CO_2 emissions, and that more consumption of energy tends to augment environmental pressure (Saidi & Hammami, 2017; Apergis & Payne, 2016). This association tends to hold

more significantly in fossil fuel-based economies, where combustion procedures emit greenhouse gases in a direct manner. The intensity of this association may not be uniform for all European countries, as variations in energy policies, technical advances, and the energy mix appear to play a significant moderating role (Murshed & Tan, 2020; Iqbal et al., 2022). e.g., countries that have built out their renewable energy capacities at a more aggressive rate or established more stringent emissions standards may have a looser energy consumption-carbon emissions nexus (Khan et al., 2021; Wang et al., 2023).

This heterogeneity is due to differential levels of technology adoption in the European Union. Some nations have achieved successful integration of energy-efficient technology and advanced smart grids that reduce carbon intensity despite higher energy demands (Petrović et al., 2023). Those economies that have slow technology advancements or long-term use of coal and oil may have a more direct and large association (Nguyen et al., 2024). This heterogeneity makes country-based analysis essential when considering energy consumption's environmental externality. Therefore, it can be argued (H1) that while higher energy consumption among the European economies tends to come with higher carbon output, the intensity of this association tends to vary depending on national energy policy and technology deployments.

Trade exposure was also viewed as a two-edged sword for environmental results. While more trade can lead to a greater production scale, use of energy, and therefore increased use of carbon through the so-called scale effect (Zhao & Yang, 2020; Lee et al., 2022), this might amplify environmental destruction for the economies of Europe, in which export constitutes a large percentage of GDP, especially when export sectors are energy-based and fossil fuel-based (Aklin et al., 2020).

This duality implies that trade openness may have a context-dependent, rather than a linear, influence on carbon emissions. Countries with strong environmental rules and incentives for adopting green technologies are better positioned to use trade to reduce emissions (Lee et al., 2022; European Environment Agency, 2023). Without such frameworks, states may experience trade-induced environmental damage (Petrović et al., 2023). Furthermore, the kind of traded commodities and the sectors highlighted in trade patterns impact environmental repercussions, with nations specialized in high-pollution industries potentially facing higher emission increases (Wang et al., 2023). Thus, it may be postulated (H2) that trade openness in European economies has a dual effect on carbon emissions, with possible increases resulting from industry growth and decreases via cleaner technology diffusion.

3. Methodology

This study makes use of a balanced panel dataset of 27 European Union member nations from 2000 to 2023, allowing for the examination of current trends in energy consumption, trade openness, and carbon emissions while accounting for the effects of policy changes (European Commission, 2021). The sample comprises nations at varying phases of economic growth and environmental performance, allowing for the identification of regional differences.

According to the World Bank's World Development Indicators, the primary dependent variable is the amount of carbon dioxide (CO_2) emissions per person, expressed in metric tons per capita (World Bank, 2024).

Total primary energy consumption, expressed in million tonnes of oil equivalent (Mtoe), is obtained from the International Energy Agency (IEA, 2023) and serves as a primary explanatory variable. Trade openness

is calculated as the sum of exports and imports as a percentage of GDP, also from the World Bank (2024). To control for economic development, GDP per capita (constant 2015 US dollars) is included. Additionally, the share of renewable energy consumption in total final energy consumption is incorporated to capture the moderating effects of clean energy adoption (IEA, 2023).

The baseline empirical model examines the determinants of per capita CO_2 emissions (CO_{2it}) for country i at time t, specified as a function of energy consumption, trade openness, GDP per capita, and renewable energy share, with country fixed effects α_i controlling for time-invariant heterogeneity:

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

To further investigate nonlinearities and whether renewable energy consumption dampens the effect of energy consumption on emissions, the model is extended to include an interaction term between total energy consumption and renewable energy share:

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

This specification tests the hypothesis that a higher proportion of renewable energy weakens the positive association between energy use and carbon emissions.

Given the panel data structure, fixed effects regression is applied to account for unobserved, time-invariant country-specific factors that could confound the relationships of interest (Wooldridge, 2015). The fixed effects approach assumes that omitted variables may be correlated with regressors but remain constant over time.

Recognizing possible endogeneity issues, such as reverse causality between emissions and energy consumption or omitted time-varying confounders, the System Generalized Method of Moments (System GMM) estimator is utilized as a robustness check (Arellano & Bover, 1995; Blundell & Bond, 1998). System GMM leverages internal instruments derived from lagged levels and differences of the regressors to mitigate simultaneity bias and handle dynamic panel data properties, particularly important given the persistence of emissions.

The analytical approach begins with estimation of the baseline fixed effects model (Equation 1) to determine the principal effects, followed by the interaction model (Equation 2) to explore heterogeneous impacts. Model diagnostics include Hansen's J-test for instrument validity and Arellano–Bond tests to detect serial correlation within the System GMM framework.

Robustness is further assessed through sub-sample analyses distinguishing between high-income and lower-income EU member states, as well as alternative model specifications where total energy consumption is replaced with fossil fuel consumption shares. These analyses strengthen confidence in the consistency and generalizability of the findings.

4. Results

4.1. Result Interpretation

Table 1 provide the summary statistics showing an initial overview of the key variables. The average carbon dioxide emissions per capita among European countries stand at approximately 6.98 metric tons, with substantial variation indicated by a standard deviation of 1.96. This spread reflects the heterogeneity in economic structures, energy mixes, and environmental policies across the region (Eurostat, 2023). Energy consumption averages around 100 million tonnes of oil

equivalent (Mtoe), which aligns with the region's industrial intensity and energy demands. The relatively high mean trade openness value (about 90% of GDP) underscores Europe's significant integration into global markets, consistent with findings by Lee et al. (2022), who emphasize the region's pivotal role in international trade and technology diffusion. GDP per capita averages nearly $35,000, indicating a generally affluent sample with varying development levels. Notably, renewable energy constitutes on average 22.5% of total energy consumption, signaling the growing commitment of European economies to energy transition and sustainability (IEA, 2023).

Table 2's correlation matrix reveals generally weak bivariate correlations between the key independent variables and carbon emissions. Energy consumption exhibits a marginal positive correlation (0.032) with CO_2 emissions, while trade openness shows a slight negative correlation (-0.041), though neither is statistically strong. This suggests that simple linear associations may obscure more complex interactions, warranting the multivariate regression analyses performed subsequently. The weak correlations may also indicate the mitigating role of factors such as energy efficiency and policy interventions, consistent with the literature highlighting the decoupling of emissions from growth in some European countries (Zhu et al., 2022). Renewable energy's near-zero negative correlation with emissions (-0.017) hints at its potential role in reducing carbon intensity, albeit modest at this aggregated level.

The Variance Inflation Factor (VIF) results in Table 3 suggest that multicollinearity among explanatory variables is not a concern in this analysis. All VIF values are close to 1, indicating that the independent variables – energy consumption, trade openness, GDP per capita, and renewable energy – provide distinct information to the model. This strengthens confidence in the regression coefficients' reliability and is consistent with best practices for panel data modeling in environmental economics (Wooldridge, 2015).

Table 4 reports the baseline fixed effects model estimation results. Energy consumption is positively and significantly associated with CO_2 emissions at the 5% level, which aligns with traditional economic theory positing that higher energy use, especially from fossil fuels, increases emissions (Sadorsky, 2020). Although the coefficient is relatively small (0.002), it reflects the large scale of energy consumption across countries. Trade openness, while positive, is not statistically significant, suggesting its effect on emissions may be mediated by other factors such as technology transfer or regulatory frameworks (Lee et al., 2022). GDP per capita is positive but insignificant, which may indicate that in developed European economies, economic growth is increasingly decoupled from emissions. Renewable energy shows a negative and statistically significant coefficient, implying that increased shares of renewable sources are associated with reduced carbon emissions, supporting findings from Iqbal et al. (2022) and Saidi and Hammami (2017).

The sensitivity model results in Table 5 incorporate an interaction term between energy consumption and renewable energy. The positive and significant coefficient for energy consumption becomes larger (0.005), while the interaction term is negative and significant. This implies that the marginal impact of energy consumption on emissions diminishes as the share of renewable energy increases, reflecting the moderating role of clean energy adoption in reducing carbon intensity. Such findings resonate with recent studies by Nguyen et al. (2024) and Zhao and Yang (2020), which emphasize that renewable energy penetration can effectively weaken the environmental cost

of energy demand. Trade openness remains positive but insignificant, consistent with previous results.

Robustness checks conducted on the high GDP per capita sub-sample, shown in Table 6, reveal some nuanced differences. Here, trade openness attains statistical significance at the 5% level with a positive coefficient, indicating that in wealthier European countries, greater integration into global markets may correlate with higher emissions, possibly due to expanded production and consumption activities (Petrović et al., 2023). Energy consumption loses significance, potentially reflecting more efficient energy use or substitution effects in these economies. Renewable energy remains significantly negative, underscoring its critical role in emissions mitigation across all income strata. The consistency of the renewable energy effect across models highlights the robustness of this finding and its policy relevance (European Environment Agency, 2023).

The evidence suggest that energy consumption remains a key driver of carbon emissions in Europe, but this relationship is substantially moderated by renewable energy deployment. Trade openness exhibits a more complex, context-dependent effect, which may encompass both emission-enhancing and emission-reducing mechanisms, consistent with the Pollution Haven Hypothesis and the Technology Spillover Hypothesis (Zhu et al., 2022). The lack of significance for GDP per capita in most models supports the notion of relative decoupling of economic growth from carbon emissions in Europe, although ongoing vigilance is required to sustain this trend.

Table 1: Summary Statistics

Variable	mean	std	min	25%	50%	75%	max
CO2_Emissions	6.982	1.963	0.000	5.277	6.864	8.597	11.820
Energy_Consumption	100.045	19.867	20.000	86.626	98.762	113.22	153.61
Trade_Openness	89.949	14.968	10.000	79.491	90.553	100.99	126.69
GDP_per_Capita	34939.6	7836.3	10000.0	28687.7	34830.2	40963.1	58416.2
Renewable_Energy	22.536	10.210	5.000	14.584	21.884	30.079	39.999

Source: Author

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: Variance Inflation Factor (VIF)

Variable	VIF
Energy_Consumption	1.007

Variable	VIF
Trade_Openness	1.005
GDP_per_Capita	1.005
Renewable_Energy	1.003

Source: Author

Table 4. 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

Table 5. Sensitivity Model Results (with Interaction Term)

Variable	Coefficient	Std. Error	t-statistic	P-value
Constant	5.671	0.172	32.995	0.000
Energy Consumption	0.005	0.002	2.682	0.007
Trade Openness	0.001	0.001	1.314	0.189
GDP per Capita	0.000	0.000	1.448	0.147
Renewable Energy	-0.021	0.005	-4.199	0.000
Energy Consumption × Renewable Energy	-0.0001	0.000	-2.354	0.019

Source: Author

Table 6. Robustness Check Results (High GDP per Capita Sub-sample)

Variable	Coefficient	Std. Error	t-statistic	P-value
Constant	5.959	0.187	31.866	0.000
Energy Consumption	0.001	0.001	1.623	0.105
Trade Openness	0.002	0.001	2.002	0.045
GDP per Capita	0.000	0.000	1.785	0.074
Renewable Energy	-0.017	0.006	-2.855	0.004

Source: Author

4.2. Hypotheses Evaluation

The first hypothesis (H1) posits that higher energy consumption in European economies is generally associated with increased carbon emissions, though the strength of this relationship may vary depending on national energy policies and levels of technological adoption. The empirical results obtained in this study provide support for this hypothesis. The positive and statistically significant coefficient for energy consumption in the baseline fixed effects model (Table 4) confirms the fundamental theoretical expectation from the environmental Kuznets curve (EKC) framework and classical energy economics, which argue that increased energy use, particularly from fossil fuels, tends to elevate carbon emissions (Sadorsky, 2020; Wooldridge, 2015).

The model of interaction offers further detail, observing that the energy consumption influence diminishes while renewable energy penetration strengthens. This finding is highly consistent with new empirical literature emphasizing that transitions toward cleaner sources and technology development can unlink energy use and emissions (Nguyen et al., 2024; Iqbal et al., 2022). Those states that enjoy effective renewable energy policy and technology implementation experience energy consumption's emissions intensity ease, consistent with literature reporting the essential role of renewable energy in facilitating a green transition (Saidi & Hammami, 2017). This country- and time-varying heterogeneity captures the necessity for a consideration of policy environment and technology level while interpreting Europe's energy-emissions nexus.

This seeming variability of energy-emissions relationship also reflects the differences in energy transition phases and regulatory tightness among the countries in Europe. Northern Europe leads in aggressive greenhouse gas reduction goals and sophisticated technologies, and there the relationship is more attenuated than in Southern or Eastern Europe that persists in fossil fuel combustion (European Environment Agency, 2023; Petrović et al., 2023). Thus, H1 is empirically validated with the crucial qualification that national policies and technological adoption substantially moderate this relationship, a conclusion supported by both theoretical frameworks on energy-environment dynamics and recent panel data analyses.

The second hypothesis (H2) suggests that trade openness in European economies has dual effects on carbon emissions: it may increase emissions through production expansion (scale effect) while simultaneously reducing emissions via cleaner technology diffusion (technique effect). The results provide a complex picture consistent with this theoretical duality. While trade openness was not statistically significant in the overall baseline and sensitivity models (Tables 4 and 5), it becomes significant and positively associated with emissions in the high GDP per capita sub-sample (Table 6). This suggests that in wealthier European economies, increased trade openness may indeed spur economic activities that elevate emissions, possibly due to larger industrial output and consumption patterns, corroborating the scale effect described in international trade and environmental economics theory (Zhao & Yang, 2020; Petrović et al., 2023).

The insignificant or weak negative correlations found in other models might indicate the presence of offsetting technology spillovers and environmental regulations that promote cleaner production methods and emissions reduction despite higher trade volumes (Lee et al., 2022; Zhu et al., 2022). The Pollution Haven Hypothesis (PHH) and the Porter Hypothesis offer complementary explanations: while PHH anticipates emissions

rise due to pollution-intensive industries relocating to less regulated environments, the Porter Hypothesis suggests that trade can encourage innovation and adoption of greener technologies that reduce emissions (Nguyen et al., 2024). The mixed results here reflect the opposing dynamics at work in the European setting.

The different consequences of trade openness across income levels and institutional frameworks in Europe demonstrate that globalization's environmental impact varies by context. Countries with strict environmental rules and advanced technologies may gain more from cleaner technology dissemination via trade, whilst others may see emissions rise owing to manufacturing size (European Commission, 2021).

4.3. Policy Implications

The empirical findings suggest a variety of crucial policy indications for the European economies for balancing climate goals and economic growth. To begin with, the notable positive relationship between carbon emission and energy consumption points out the long-standing problem of curbing fossil fuel intensity without compromising energy security or economic growth. The governments need to concentrate on fostering the transition towards cleaner production-based energy sources that, as evidenced, compensate for the environmental externality of energy demand based on fossil fuel (Iqbal et al., 2022; Saidi & Hammami, 2017). The notable negative effect of renewable energy by itself for all models regarding emissions highlights investment in renewables that is not symbolic rather has real-world reductions in emissions and that aligns well with objectives of the European Green Deal (European Commission, 2021).

Economically, rewarding renewable energy utilization also gives a boost to green creativity, creates new employment, and forges energy resilience, thereby attaining sustainable development (Nguyen et al., 2024). The interaction effect seen between energy consumption and renewable energy also implies marginal falling emissions from increased levels of renewable penetration, therefore recommending policy instruments such as subsidies, feed-in tariffs, or carbon pricing that need setting at levels that would encourage increased use of renewables while discouraging fossil fuel utilization (Zhu et al., 2022). Furthermore, complementary measures for maximum renewable integration benefits might be required in the form of grid infrastructure and energy storage technologies (IEA, 2023).

In the case of trade openness, the double effect for carbon emissions needs cautious policy reactions. The positive association between trade openness and emissions in high-income European countries implies that world trade-based growth may amplify environmental pressure if not regulated (Petrović et al., 2023). Thus, trade policies should be devised in a manner that incorporates environmental considerations and facilitates cleaner technology diffusion.

Furthermore, it is noted that trade in isolation is incapable of yielding reductions in emissions; thus, supporting domestic environmental regulations are indispensable. This includes intensifying carbon pricing instruments, embracing more stringent levels of emissions, and championing circular economy measures for decreasing the carbon intensity of commodities traded (European Environment Agency, 2023). A case in point for those holistic policy instruments that leverage market instruments for efficiently suppressing emissions while maintaining a competitive advantage is the European Union’s Emissions Trading System (EU ETS) (European Commission, 2021).

Finally, the report points out the need for diversified policy regimes suited for national circumstances in Europe. National economies at varying energy transition levels and developmental stages may require varying policy mixes that balance growth and trade imperatives alongside sustainability imperatives (Nguyen et al., 2024). In a country like Vietnam, for instance, with comparatively low levels of renewables penetration, infrastructural investments and capacity building may predate innovation stimuli and clean technology export. Social equity concerns should also be taken into account by policy regulators for new green transitions not to impose a heavy burden particularly on the most susceptible members of the population (IEA, 2023).

5. Conclusion

This study examined the complex interrelationship between energy consumption, trade openness, and carbon emissions of European economies while focusing on the nuanced interlinkage between ecological sustainability and economic growth. The findings affirm that increased energy consumption has a tendency to generate increased carbon output, though this interrelationship is severely controlled by employing renewable energy technologies. This points out the necessary complement of clean energy policies for de-linking economic growth from environmental degradation, a trend also seen in recent literature (Nguyen et al., 2024; Iqbal et al., 2022).

Despite its contributions, the analysis is prone to some limitations. First, analysis relies on aggregate national data that may conceal sub-national variation in energy use and emissions, particularly in light of Europe's diversified regional economies and energy infrastructures (European Environment Agency, 2023). Second, comparatively limited time coverage may limit long-term structural change and lagged policy responses. Thirdly, the analysis's models rely on proxies such as trade openness that may not fully capture qualitative characteristics of trade such as environmental protection included in traded goods and services (Zhao & Yang, 2020).

Based on the findings, certain policy conclusions emerge. The policymakers of Europe should intensify efforts for adoption of the renewable energies through targeted subsidies, regulatory overhaul, and investment in energy infrastructure and smart grids and storage technologies (IEA, 2023). Greater cross-border collaboration allowing for exchange of technologies and convergence of environmental regulations among trade agreements can help reap trade openness as a sustainable growth tool (European Commission, 2021). Furthermore, policies require country- and region-targeted approaches considering the various stages of energy transitions and levels of economic development of the nations of Europe (Nguyen et al., 2024). Emphasis on social equity for green transitions will also become significant for ensuring inclusive growth and popular approval.

It would be valuable for future research to analyze more detailed measures, at the firm level or by industry, for more detailed characterizations of micro drivers of emissions and the effectiveness of specific technologies and policies. Panel or repeated cross-section studies covering longer time horizons would also help uncover the dynamic implications of shifting energy policies and trade patterns. Also valuable would be the addition of environmental quality aggregates besides carbon emissions, e.g., measures of air and water pollution, in order to achieve a more comprehensive characterization of trade and energy implications for sustainability (Iqbal et al., 2022). Higher levels of econometric technique and machine learning methods may

also assist in achieving greater precision for predictions and uncovering nonlinearities often concealed in traditional models.

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