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Effects of Oil Price Volatility and Trade Development Intensity on Renewable Energy Consumption in Oil-Importing and Oil-Exporting Countries

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ABSTRACT

This study aims to examine the effects of oil price volatility and trade development intensity on renewable energy consumption in major oil-importing and oil-exporting countries between 2001 and 2022. This research employs a comparative panel-data approach using annual data from 10 major oil-importing and 10 major oil-exporting countries over the period 2001–2022. Oil price volatility was estimated using the EGARCH model to capture asymmetric fluctuations in global oil markets. The main empirical analysis was conducted using the Generalized Method of Moments (GMM) to address endogeneity, serial correlation, and heteroskedasticity within dynamic panel structures. Stationarity was assessed using the Levin–Lin–Chu (LLC) unit root test, while the Kao cointegration test was applied to evaluate long-run equilibrium relationships among renewable energy consumption, trade development, oil price volatility, innovation, and human development. Additional diagnostic tests, including the Hansen J-statistic and Arellano–Bond AR(1)/AR(2) serial correlation tests, were applied to confirm model validity and instrument robustness. In oil-importing countries, trade development intensity, innovation, oil price volatility, and human development all exhibited positive and significant effects on renewable energy consumption, with strong dynamic persistence indicated by the lagged dependent variable. In contrast, for oil-exporting countries, trade development intensity and oil price volatility showed negative and significant effects, whereas innovation and human development positively influenced renewable energy consumption. The lagged dependent variable was also significant, reflecting structural inertia in renewable energy transition processes across both groups. All models passed diagnostic tests confirming instrument validity and absence of second-order serial correlation. The findings highlight fundamentally different renewable energy transition pathways between oil-importing and oil-exporting countries, shaped by structural dependencies, trade profiles, and exposure to oil market volatility.

Keywords: *oil price, trade development, renewable energy, innovation*

1. Introduction

The accelerated global shift toward renewable energy has emerged as one of the most pressing strategic, economic, and environmental imperatives of the twenty-first century. Governments, industries, and international organizations increasingly recognize that dependence on fossil fuels is unsustainable given their ecological impacts, geopolitical vulnerabilities, and long-term economic risks. The renewable energy sector, therefore, has evolved into a major arena for technological innovation, institutional restructuring, and policy transformation (Tantau & Frăţilă, 2021). As nations grapple with the consequences of climate change, volatility in commodity markets, and rising energy insecurity, the need to understand the multifaceted determinants of renewable energy consumption becomes more urgent than ever. This is especially true in economies where oil price shocks, trade dynamics, financial constraints, and human capital disparities significantly shape the trajectory of clean energy adoption.

The economic and environmental complexities of transitioning from non-renewable to renewable energy systems have been extensively documented in the literature. Many developing Asian economies face difficult trade-offs between maintaining short-term economic growth and achieving long-term sustainability, particularly as they navigate structural transitions in their energy portfolios (Mohsin et al., 2021). While renewable energy has been consistently linked to reduced carbon emissions and more stable growth trajectories, the pathways toward its widespread adoption differ substantially depending on institutional capacity, financial development, innovation systems, and the interplay between domestic and international markets (Shahbaz et al., 2021). At the same time, rapid global technological advancements and declining costs of renewable technologies have altered the competitive landscape of the energy sector, making clean energy both accessible and strategically valuable for economies at different development stages (Wood, 2019).

Among the most significant challenges affecting renewable energy expansion is the volatility of oil markets. Oil prices directly influence national energy strategies, particularly in oil-dependent regions where fossil fuel revenues shape fiscal stability, investment behavior, and the relative attractiveness of renewable energy projects. Research demonstrates that oil-dependent nations often face structural barriers to energy diversification due to resource-based economic models, institutional inertia, and fluctuating foreign exchange earnings (Fossaceca, 2020). At the same time, renewable energy diversification becomes even more critical for these countries as economic vulnerability to oil price shocks persists. For low- and middle-income countries, trade liberalization policies and global integration have been shown to either support or hinder renewable energy expansion depending on policy alignment and economic structure (Murshed, 2020).

Human capital performance and development levels also play a central role in shaping the transition toward renewables. The Human Development Index (HDI), which integrates dimensions of education, health, and living standards, has been identified as a critical predictor of clean energy adoption. Countries with higher HDI scores typically demonstrate greater capacity to absorb technological innovations and implement environmentally responsible policies (Alvarado et al., 2021). In oil-dependent economies, the relationship between human development and renewable energy is even more pronounced, as the availability of skilled labor, environmental awareness, and institutional quality directly affect the pace of energy diversification and the success of long-term sustainability goals (Fossaceca, 2020).

Innovation systems, including technological capabilities and financial mechanisms, are also crucial determinants of renewable energy development. The expansion of global innovation networks and investment in clean energy technologies significantly enhance the capacity of countries to develop and deploy renewable infrastructure. Studies highlight that innovation-driven economies are more resilient and more capable of transitioning away from carbon-intensive energy structures due to their stronger technological foundations and adaptive institutional environments (Xu et al., 2024). Furthermore, the contribution of innovation extends beyond technological advancement to include new financing mechanisms such as green bonds, Islamic climate bonds, and financial leasing systems, which help reduce investment risk and accelerate renewable energy deployment (Achyar, 2025; Xie & Lin, 2025). Governments and private sector institutions increasingly integrate these tools to stimulate clean energy investment and support long-term climate objectives (Rehman et al., 2025).

The importance of trade development in shaping renewable energy consumption has gained increased scholarly attention. Regions that engage more deeply in international trade gain access to advanced technologies, cleaner production systems, and knowledge spillovers that can significantly reduce non-renewable energy consumption and increase renewable energy capacity (Adebayo et al., 2021). However, the effects of trade openness are not uniform. In some oil-exporting economies, trade intensity sustains dependence on fossil fuel exports and undermines incentives to diversify into renewable energy markets, thereby creating a structural contradiction between economic openness and sustainability transitions (Hoang, 2020). Diverging trade patterns, therefore, challenge assumptions regarding the universal benefits of globalization for the clean energy transition.

Financial development has been found to exert both direct and indirect effects on renewable energy demand. Adequate financial infrastructure encourages investment in clean technologies, reduces financing costs, and enhances the feasibility of large-scale energy projects (Anton & Nucu, 2020). Meanwhile, politically stable environments and effective regulatory frameworks amplify the positive influence of financial development, particularly in emerging economies where institutional weaknesses can hinder renewable energy progress (Rehman et al., 2025). The interaction between financial development, policy support, and renewable energy consumption thus forms a crucial area of inquiry, especially in countries characterized by economic instability or high oil dependency.

Several studies emphasize the intertwined relationship between economic development, human capital, and renewable energy consumption. Higher development levels tend to reduce dependence on non-renewable energy sources and increase the capacity of countries to pursue sustainability-driven energy strategies (Bamati & Raoofi, 2020). In addition, research on clean energy investment behavior in China suggests that market configuration, total factor productivity, and supply chain structures significantly influence renewable energy deployment (Lin & Zhu, 2025). National strategies that promote efficiency improvements and integrate renewable energy production into broader economic reforms appear to yield higher long-term benefits.

Furthermore, the rise of green hydrogen, electric vehicles, and other emerging clean technologies adds new layers of complexity to national energy transitions. Recent analyses highlight that countries in transition, including Iraq, confront multifaceted challenges in balancing economic resilience with the pursuit of renewable energy goals (Qusay et al., 2025). The expansion of renewable energy requires not only technological capacity but also institutional readiness, governance reforms, and coordinated policy efforts capable of addressing market volatility and structural dependence on fossil fuels.

International evidence underscores that renewable energy consumption is also shaped by development stages. Panel cointegration analyses show that renewable energy consumption, carbon emissions, and economic development are deeply interconnected across both advanced and emerging economies (Nguyen & Kakinaka, 2019). At the same time, global competitiveness studies illustrate how renewable energy technologies continue to evolve rapidly, transforming regional power markets and reshaping geopolitical alliances (Wood, 2019). Such dynamics highlight the importance of studying renewable energy transitions from a multidimensional perspective that integrates economic, environmental, technological, and institutional determinants.

The conceptualization of energy transition has expanded to include environmental taxation, governance structures, and cross-sectoral policy integration. Research emphasizes that effective environmental taxation can serve as a strategic tool to incentivize renewable energy consumption and reduce carbon emissions in developing economies (Rehman et al., 2025). Similarly, digital transformation, smart infrastructure, and intelligent energy systems in buildings create additional opportunities for optimizing renewable energy production and use (Tamimi & Farhang, 2025). The incorporation of intelligent systems fosters efficiency and helps countries manage energy demand more effectively, reducing reliance on traditional fossil fuel systems.

Additionally, renewable energy transitions are increasingly linked to global climate goals and sustainable financing frameworks. Islamic climate bonds, for instance, represent an innovative mechanism for mobilizing capital toward clean energy projects in ways that align with cultural and ethical norms in Muslim-majority regions (Achyar, 2025). These financing strategies underscore the growing interplay between sustainability, finance, governance, and cultural dimensions in shaping renewable energy pathways.

Lastly, the emerging literature highlights growing complexities in metal–oil market interactions—an area that will increasingly influence the cost structures and strategic feasibility of renewable technologies. As clean energy technologies become more mineral-intensive, fluctuations in metal markets may affect renewable energy costs and adoption rates, especially in economies confronted with both domestic and global market pressures (Akinci Tok, 2025). This underscores the need for more holistic analyses that integrate resource market dynamics into renewable energy policy research.

Given these global dynamics, a critical research gap remains concerning how oil price volatility and trade development intensity jointly influence renewable energy consumption in oil-importing versus oil-exporting countries. While existing studies offer valuable insights into determinants of renewable energy, few have directly compared how structural differences between these country groups shape their renewable energy trajectories. Addressing this gap is essential for designing targeted policy interventions capable of supporting sustainable energy transitions across heterogeneous economic contexts.

The aim of this study is to examine the effects of oil price volatility and trade development intensity on renewable energy consumption in oil-importing and oil-exporting countries.

2. Methods and Materials

The research model, based on the model of Amri & Nguyen (2019) with minor modifications, is specified as follows:

$REit = β0 + β1Oilpit + β2Developit + β3Innoit + β4Hdiit + εit$

RE: Renewable energy. To measure this variable, the renewable energy consumption index from the data available at www.EIA.org was used.

Oilp: Oil price. To measure this variable, Brent crude oil prices available in the BP database were used.

Develop: Trade development intensity. This variable was measured using the ratio of imports plus exports to gross domestic product (GDP). Data were obtained from the World Bank website (worldbank.org).

Inno: Global Innovation Index. To measure this variable, the technological innovation indicator was used, extracted from the World Bank database (worldbank.org).

Hdi: Human Development Index. The Human Development Index (HDI) is one of the most widely used indicators by several international organizations to assess the development status of countries. HDI provides a single composite index representing three key dimensions of human development: a long and healthy life, access to knowledge, and a decent standard of living.

To measure oil price volatility and extract the uncertainty index required for the dynamic panel model, the EGARCH heteroskedasticity model was first estimated. The choice of this approach is important because the behavior of the oil market—particularly in oil-exporting countries—is typically characterized by external shocks, spillover effects, and significant volatility. Therefore, assuming constant variance or symmetry in classical models would not accurately reflect real market dynamics. The EGARCH model, by allowing asymmetric volatility and different responses of variance to positive and negative shocks, captures the structural characteristics of the oil market with greater precision. Moreover, this model ensures that conditional variance remains positive even in the presence of severe shocks, while incorporating jump-like behavior in oil prices without imposing restrictive parameter constraints. For this reason, the EGARCH model was employed in this study to extract the oil price uncertainty index, which is subsequently used as a key variable in the dynamic panel model of oil-exporting countries. The estimation results are presented in the following table.

Table 1

EGARCH Model Estimation

Variable Symbol	Coefficient	Std. Error	Test Statistic	Probability
C	25.86	1.93	13.36	0.00
OILP(-1)	0.69	0.04	16.10	0.00
Variance Equation				
C(3)	4.33	0.01	566.22	0.00
C(4)	-2.11	0.04	-52.05	0.00
C(5)	0.43	0.14	3.14	0.00
R-squared	0.50	Mean dependent var	67.19	
Adjusted R-squared	0.47	S.D. dependent var	25.55	
S.E. of regression	18.58	Akaike info criterion	8.53	
Sum squared resid	6557.48	Schwarz criterion	8.83	
Log likelihood	-83.60	Hannan-Quinn criter.	8.60	
Durbin-Watson stat	1.60			

The results of the EGARCH model estimation for oil price indicate that this time series, in addition to exhibiting autoregressive behavior in the mean equation, also displays conditional heteroskedasticity and asymmetric effects. The mean equation shows a strong dependence of oil prices on their lagged values, as the coefficient of the lagged oil price variable is 0.69 and statistically significant. This indicates that oil prices during the study period followed a persistent and self-reinforcing pattern, with a major portion of their fluctuations driven by shocks from previous periods. The constant term in the mean equation is also significant, determining the baseline level of oil prices.

In the variance equation, the estimated coefficients clearly demonstrate asymmetric behavior and differing effects of positive and negative shocks on oil price volatility. The coefficient of the asymmetric term (5), which is positive and statistically significant at approximately 0.43, indicates that positive oil price shocks (such as sudden increases in global oil prices) have a stronger effect on increasing volatility, and the conditional variance responds more sharply to such shocks. In contrast, the coefficient (4), representing the effect of standardized absolute shocks, is negative with a large absolute value, suggesting that negative shocks exert a different and dampening effect on volatility, thereby demonstrating an asymmetric reaction.

The combined coefficients of the variance equation indicate that the oil market during the study period exhibited a structurally volatile and asymmetric behavior, where positive shocks intensified volatility more strongly than negative shocks, which produced more moderate responses. Such a pattern is consistent with known characteristics of the global oil market, particularly its sensitivity to geopolitical events, supply disruptions, and changes in global demand. Furthermore, the persistence of the variance process indicates that oil market uncertainty during this period had a lasting nature and its reduction would require fundamental transformations in supply and demand dynamics.

Overall, the EGARCH model results provide a reliable and econometrically validated measure of oil price uncertainty, which is subsequently used as a main variable in the dynamic panel model employed in the continuation of this research.

3. Findings and Results

Frequency distribution tables and charts serve as effective tools for organizing and visually presenting data. Measures of central tendency (such as mean, median, and mode) provide a representation of the central point of the data distribution by summarizing a dataset into a single value or representative number. Measures of dispersion, including standard deviation, range, and variance, indicate the extent to which data are spread around the central value. Overall, appropriate use of descriptive statistics makes it possible to clearly express the characteristics of the data, facilitates a better understanding of subsequent test results, and enables comparison of findings with other studies.

In Table (2), the descriptive statistics of the research variables based on annual data for the period 2001 to 2021, calculated using EViews software, are presented:

Table 2

Descriptive Statistics of Research Variables

Oil-Importing Countries								
Variable	Symbol	Mean	Median	Max	Min	Std. Dev.	Skewness	Kurtosis
Trade Development Intensity	DEVELOP	57.76	56.37	85.49	37.68	10.14	0.52	2.90
Human Development Index	HDI	0.91	0.88	1.39	0.62	0.18	0.76	2.80
Global Innovation Index	INNO	53.57	53.48	88.49	18.89	15.89	-0.04	2.46
Oil Price Volatility	OILP	0.15	0.08	0.89	0.02	0.20	2.62	8.93
Renewable Energy	RE	1.09	1.07	1.64	0.49	0.24	0.14	2.45
Oil-Exporting Countries								
Variable	Symbol	Mean	Median	Max	Min	Std. Dev.	Skewness	Kurtosis
Trade Development Intensity	DEVELOP	78.91	78.18	118.55	43.97	15.87	0.24	2.52
Human Development Index	HDI	0.97	0.92	1.51	0.67	0.20	0.72	2.66
Global Innovation Index	INNO	74.27	73.60	123.55	25.46	22.52	-0.01	2.41
Oil Price Volatility	OILP	0.15	0.08	0.89	0.02	0.20	2.62	8.93
Renewable Energy	RE	1.09	1.07	1.64	0.49	0.24	0.13	2.47

Based on the table above, the mean, median, maximum and minimum values, along with the standard deviation of each research variable, are separately reported. The most important measure of central tendency is the mean, which reflects the central point of the data distribution, while the standard deviation, as the principal measure of dispersion, indicates the degree of variability around the mean. Additionally, maximum and minimum values represent the range of variation for each variable during the study period.

One of the fundamental prerequisites in estimating time-series econometric models is the examination of variable stationarity. A stationary time series is one in which the mean, variance, and autocovariances remain constant over time. In contrast, non-stationary variables (with trends) may lead to spurious regressions and misleading inferences. Therefore, ensuring the stationarity of variables prior to further analysis is essential.

To examine this, unit root tests such as the Levin-Lin-Chu (LLC) test are used. This test evaluates the null hypothesis of the presence of a unit root (non-stationarity). If the test statistic is smaller than the critical value and/or the p-value is less than the chosen significance level (typically 5%), the null hypothesis is rejected and the time series is considered stationary.

Below are the results of the stationarity test for the research variables:

Table 3

Stationarity Results

Country Group	Variable	Symbol	Test	LLC Test Statistic	Probability	Result
Oil-Exporting Countries	Trade Development Intensity	DEVELOP	Level	-456213.11	0.00	Stationary
	Human Development Index	HDI	Level	-38234.33	0.00	Stationary
	Global Innovation Index	INNO	Level	-490982.78	0.00	Stationary
	Oil Price Volatility	OILP	Level	-10.54	0.00	Stationary
	Renewable Energy	RE	Level	-101560.25	0.00	Stationary
Oil-Importing Countries	Trade Development Intensity	DEVELOP	Level	-283383.47	0.00	Stationary
	Human Development Index	HDI	Level	-51434.51	0.00	Stationary
	Global Innovation Index	INNO	Level	-274405.86	0.00	Stationary
	Oil Price Volatility	OILP	Level	-10.54	0.00	Stationary
	Renewable Energy	RE	Level	-101559.75	0.00	Stationary

The LLC stationarity test results for the research variables in both oil-exporting and oil-importing countries show that all variables are stationary at level. As indicated, the Levin-Lin-Chu test statistics for all series in both groups are negative, and their p-values are less than 0.05, implying rejection of the null hypothesis of a unit root. Therefore, the variables of trade development intensity, human development index, global innovation index, oil price volatility, and renewable energy consumption do not contain unit roots and are statistically stationary. Stationarity at level indicates that the series exhibit stable behavior and that their fluctuations are not the result of accumulated stochastic trends. Hence, the variables maintain statistical stability during the period 2001 to 2022. This allows for the use of panel data estimation methods such as the Generalized Method of Moments (GMM) without concerns about spurious regression. Moreover, since all variables are stationary, differencing or combining different integration orders is unnecessary, and the model can be estimated in levels using the main variables.

To examine the existence of a long-term equilibrium relationship among the model variables—including renewable energy consumption, human development, innovation, trade development intensity, and oil price volatility—the Kao cointegration test was used. Given that the dataset covers 10 cross-sections and the period from 2001 to 2022, the Kao test is more suitable compared to other tests such as Pedroni.

Table 4

Kao Test Results

Group	Kao Test	t-Statistic	Probability
Oil-Exporting Countries	ADF	-3.41	0.00
Oil-Importing Countries	ADF	-5.98	0.00

The results indicate that the ADF statistics derived from the residuals of the cointegration regression are -3.41 and -5.98, with corresponding p-values of 0.00. These values are significantly lower than conventional significance levels, confirming rejection of the null hypothesis of no cointegration. Therefore, it can be concluded that a stable long-term equilibrium relationship exists among renewable energy consumption, human development, innovation, trade development intensity, and oil price volatility for both groups of countries.

The regression model was estimated using the GMM method for both oil-importing and oil-exporting countries. The Generalized Method of Moments is suited for models where classical linear regression assumptions—such as homoscedasticity, absence of autocorrelation, and full exogeneity of variables—do not hold. By employing appropriate instruments, GMM provides consistent and efficient coefficient estimates in the presence of endogeneity, serial correlation, and heteroskedasticity. The primary advantage of GMM is that, unlike classical methods, it does not require specific distributional assumptions for the error term and relies only on moment conditions. In dynamic panel models, where the dependent variable exhibits temporal dependence and the inclusion of lagged dependent variables introduces Nickell bias, ordinary least squares methods are inappropriate.

Table 5

Estimation Results for Oil-Importing Countries

Variable	Symbol	Coefficient	Std. Error	Test Statistic	Probability
Renewable Energy	RE(-1)	0.30	0.06	4.66	0.00
Trade Development Intensity	DEVELOP	0.02	0.01	2.33	0.02
Global Innovation Index	INNO	0.02	0.01	2.58	0.02
Oil Price Volatility	OILP	0.18	0.08	2.17	0.03
Human Development Index	HDI	0.64	0.38	1.68	0.09
J-statistic		12.47	S.E. of regression	0.1180	
Prob(J-statistic)		0.28	Instrument rank	9	

4. Discussion and Conclusion

The findings of this study provide important empirical insights into the determinants of renewable energy consumption in both oil-importing and oil-exporting economies, emphasizing the role of oil price volatility, trade development intensity, human capital, and innovation capacity. The positive and significant coefficient of the lagged dependent variable in both country groups indicates a strong degree of inertia and structural continuity in renewable energy transitions. This dynamic behavior is consistent with prior evidence showing that renewable energy trajectories evolve gradually and require long-term policy, financial, and infrastructural commitments (Nguyen & Kakinaka, 2019). The persistence observed in the renewable energy variable aligns with the argument that clean energy systems rely on accumulated technological learning, institutional maturity, and progressive integration into national energy portfolios (Tantau & Frăţilă, 2021). Therefore, the presence of strong dynamic effects reinforces the interpretation that renewable energy transitions are path-dependent processes shaped by historical investments and policy choices.

The results for oil-importing countries demonstrate that trade development intensity positively influences renewable energy consumption. This finding corresponds with previous studies showing that increased integration into global markets often facilitates access to advanced low-carbon technologies, enhances supply chain efficiencies, and encourages the adoption of cleaner energy sources (Adebayo et al., 2021). In particular, energy-importing countries tend to rely on imported renewable technologies and equipment to diversify their energy portfolios, and increased trade openness facilitates these flows. This supports the broader literature indicating that globalization can act as a catalyst for renewable energy expansion when complemented by appropriate policy frameworks (Murshed, 2020). Furthermore, the positive association between trade development and renewable energy consumption echoes evidence from technology diffusion literature, which highlights the importance of international networks in supporting rapid adoption of clean technologies (Xu et al., 2024). These converging findings underscore the critical role of trade openness for countries that lack sufficient domestic energy resources.

Similarly, the positive effect of innovation on renewable energy consumption in oil-importing economies aligns with findings that modern energy transitions are fundamentally driven by technological progress and research-led productivity improvements. Innovation enhances the efficiency of renewable technologies and reduces costs over time, enabling wider adoption (Lin & Zhu, 2025). Moreover, the observed significance of innovation supports earlier research showing that higher innovation capacity contributes to reducing non-renewable energy consumption and accelerates the shift toward cleaner alternatives (Bamati & Raoofi, 2020). The findings also reinforce the argument that economies at higher technological development stages can more effectively exploit renewable energy opportunities through high-performing supply chains, improved technological absorption, and sophisticated industrial structures (Wood, 2019). Thus, the evidence suggests that sustained technological innovation remains an essential driver of clean energy transformation.

Oil price volatility exhibits a positive and significant influence on renewable energy consumption among oil-importing countries. This result corroborates earlier studies suggesting that oil-importing nations respond to rising uncertainty in global oil markets by diversifying their energy portfolios and investing more heavily in renewable sources (Qiu et al., 2020). Frequent fluctuations in oil prices increase the cost of energy imports and amplify macroeconomic risks, prompting policymakers to seek more stable and sustainable alternatives. This aligns with the broader literature indicating that energy security concerns often accelerate clean energy adoption, especially in countries with high import dependency (Mohsin et al., 2021). Furthermore, the observed behavior matches findings that highlight the importance of risk mitigation and economic resilience in driving renewable energy investment in vulnerable economies (Rehman et al., 2025). The present study thus reinforces the argument that oil price instability acts as a powerful structural motivator for accelerating renewable energy transitions in import-dependent regions.

The human development index also has a positive and meaningful effect on renewable energy consumption in oil-importing economies. This supports prior evidence demonstrating that countries with higher education levels, better institutional quality, and stronger social development are more capable of adopting environmentally sustainable technologies (Alvarado et al., 2021). Human development enhances environmental awareness, increases technical capacity, and strengthens governance systems that support renewable energy adoption. Moreover, previous findings on oil-dependent nations emphasize the importance of human development in enabling structural reforms and energy diversification, particularly where institutional performance shapes energy policy effectiveness (Fossaceca, 2020). Consistent with these observations, the results of this study demonstrate that human development contributes to creating a supportive socioeconomic environment necessary for the transition toward clean energy.

In contrast, the results for oil-exporting countries reveal notably different dynamics, most prominently in the case of trade development intensity, which exhibits a negative and significant effect on renewable energy consumption. This finding resonates with studies that highlight the structural rigidity of oil-exporting economies, where increased integration into global markets reinforces fossil fuel dependency rather than encouraging diversification (Hoang, 2020). For such economies, trade intensity is largely driven by higher volumes of traditional energy exports, which can crowd out incentives to transition toward renewable energy. This interpretation aligns with research describing how oil-rich countries often face a resource-based lock-in effect that restricts investment in clean technology (Omri & Nguyen, 2019). Furthermore, the negative relationship between trade intensity and renewable energy in these countries underscores the fundamental divergence between export-based economic models and sustainability-oriented policy agendas.

Innovation exhibits a positive and significant effect on renewable energy consumption in oil-exporting economies as well, though the magnitude is smaller than in importing countries. This suggests that while innovation capacity does contribute to clean energy expansion, it may not be sufficient to counteract broader structural and institutional barriers in fossil fuel-based economies. Nevertheless, the finding is consistent with emerging evidence that innovation systems in oil-exporting countries are gradually expanding beyond hydrocarbon-centered technologies, increasingly incorporating cleaner and more sustainable technologies (Zgurskyy, 2024). In addition, recent studies document that even modest improvements in innovation capacity can generate significant spillover effects supporting renewable energy integration, particularly as technological efficiencies improve and investment risks decrease (Xu et al., 2024). These findings indicate that innovation may gradually serve as a catalyst for long-term energy diversification in oil-exporting regions.

The negative and significant coefficient of oil price volatility for oil-exporting economies contrasts sharply with the positive effect observed for oil importers. This divergence can be explained by the fact that oil price instability directly affects fiscal revenues, government budgets, and foreign exchange earnings in oil-exporting countries. As documented in prior studies, periods of oil price volatility often induce fiscal tightening, discourage long-term investments, and reduce the availability of funds for renewable energy projects (Qusay et al., 2025). Oil volatility can therefore limit the capacity of governments to allocate resources toward clean energy expansion, especially if budgetary priorities remain tied to fossil fuel sectors. Moreover, the result is consistent with findings showing that economic instability in oil-rich nations suppresses investment prospects, weakens policy continuity, and undermines institutional efforts to promote renewable energy (Mohsin et al., 2021). This underscores how structural economic dependence on hydrocarbons creates conditions in which oil volatility becomes a barrier rather than a catalyst for renewable energy development.

Human development demonstrates a positive and significant effect on renewable energy consumption in oil-exporting countries as well. This parallels findings from studies emphasizing that improvements in education, institutional quality, and social well-being contribute to stronger support for environmental policies, increased public demand for clean energy, and greater national capacity to implement renewable energy programs (Adebayo et al., 2021). Moreover, in resource-rich economies, increasing human development may enhance the quality of governance and policymaking, creating conditions conducive to overcoming entrenched fossil fuel interests (Nguyen & Kakinaka, 2019). These patterns reinforce the interpretation that human development acts as a universal facilitator of clean energy transitions, even in economies dominated by hydrocarbon sectors.

Overall, the results illustrate a clear contrast between oil-importing and oil-exporting economies. While trade openness, innovation, and oil price volatility tend to stimulate renewable energy consumption in importing countries, the same factors either weaken or complicate renewable energy trajectories in exporting nations. These divergences highlight the structural, institutional, and market-based differences that shape renewable energy pathways across countries with different energy profiles. The findings reinforce the argument that energy transition policies cannot adopt a one-size-fits-all approach, as countries vary widely in their economic dependencies, technological capacities, and institutional readiness (Tantau & Frăţilă, 2021). Moreover, the results emphasize the importance of integrated strategies that address both internal capabilities—such as innovation and human development—and external forces—such as global market volatility and trade dynamics.

This study is constrained by the availability and consistency of annual data across all selected countries, which limits the ability to examine higher-frequency fluctuations or short-term policy shocks. The analysis also relies on aggregate national indicators that may not fully capture sector-specific renewable energy trends or subnational differences. Furthermore, the study focuses primarily on economic and structural variables, and does not incorporate political, cultural, or regulatory dimensions that may influence renewable energy adoption. Finally, the distinction between oil-exporting and oil-importing countries, while analytically useful, may oversimplify hybrid cases where energy structures or trade profiles shift over time.

Future research should incorporate political governance quality, environmental regulation frameworks, and institutional strength to capture a more comprehensive picture of renewable energy transitions. Studies could also explore technology-specific dynamics, such as solar, wind, hydrogen, and electric vehicle infrastructure, to understand differentiated adoption patterns. Longitudinal case studies on major oil-exporting countries undergoing diversification programs may reveal deeper insights into the socio-political barriers to clean energy investment. Additionally, integrating climate risk indices and environmental vulnerability metrics could expand understanding of how climate exposure influences renewable energy strategies.

Policymakers should design energy transition strategies tailored to their national energy structure, particularly by strengthening innovation ecosystems and investing in human development. Oil-importing countries can accelerate renewable energy growth by leveraging trade openness to access cleaner technologies, while oil-exporting countries should diversify economic structures to reduce exposure to oil price volatility. Both groups of countries can benefit from financial innovations, long-term investment planning, and public education initiatives that support clean energy adoption.

Authors' Contributions

Authors contributed equally to this article.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

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Declaration of Interest

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Ethics Considerations

In this research, ethical standards including obtaining informed consent, ensuring privacy and confidentiality were considered.

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