The Impact of Financial Development on Carbon Emissions and Energy Consumption Patterns in OPEC Member Countries: An Econometric Analysis

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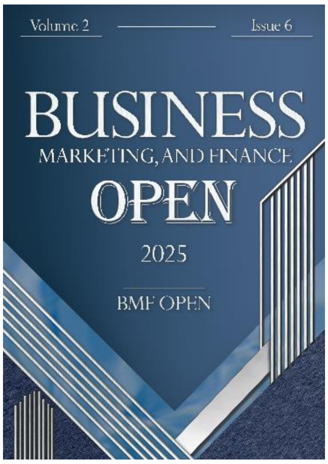

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Abstract: Energy plays a crucial role in the economic development of countries. Achieving economic development in developing nations appears unlikely without adequate energy resources. Over recent decades, energy demand has been rising due to population growth and changes in the economic structure of nations. This growing demand for fossil fuels has led to increased greenhouse gas emissions. In a pioneering approach, this study investigates the relationship between financial development, carbon emissions, and energy consumption in OPEC member countries over the period from 2013 to 2024. By employing econometric techniques such as the Generalized Method of Moments (GMM), Dynamic Ordinary Least Squares (DOLS), and Fully Modified Ordinary Least Squares (FMOLS), the results indicate that financial development in these countries has had a significant and positive impact on increased environmental pollution and energy consumption. These findings suggest that financial development in the examined countries has not led to the advancement of environmentally friendly technologies and may have even exacerbated environmental impacts by intensifying industrial activities.

Keywords: Financial Development, Energy Consumption, Environmental Pollution, OPEC Member Countries

1. Introduction

In the modern global economy, energy consumption, environmental sustainability, and financial development have emerged as interconnected dimensions that play critical roles in shaping national and regional development strategies. For countries heavily reliant on hydrocarbon exports—such as the members of the Organization of the Petroleum Exporting Countries (OPEC)—understanding the relationship between financial development, energy use, and carbon emissions is particularly vital. These nations stand at the crossroads of accelerating industrialization, rising energy demands, and the pressing global imperative to reduce greenhouse gas (GHG) emissions. This dual challenge of fostering economic growth while mitigating environmental degradation has brought the Environmental Kuznets Curve (EKC) hypothesis and its implications into renewed scholarly focus, especially in emerging and resource-rich economies.

The EKC hypothesis posits a non-linear relationship between environmental degradation and income, suggesting that environmental quality initially deteriorates with economic growth but eventually improves as income reaches higher levels and societies invest in cleaner technologies and institutions [1, 2]. Empirical validations of this theory across diverse contexts have produced mixed results. For instance, while some studies confirm the EKC hypothesis in low- and middle-income economies [3, 4], others highlight the role of mediating factors such as financial development, trade openness, and technological innovation in shaping this trajectory [5, 6].

Financial development, particularly, is often viewed as a double-edged sword in the context of environmental sustainability. On one hand, an efficient and mature financial system can mobilize capital for green technologies, renewable energy projects, and energy efficiency improvements [7-9]. On the other hand, financial expansion may also lead to an increase in energy-intensive industrial activities and consumer credit, thereby exacerbating environmental degradation [10, 11]. This ambivalence necessitates a nuanced investigation into how financial development influences carbon emissions and energy consumption in OPEC countries—nations characterized by both extensive fossil fuel reserves and growing aspirations for economic diversification.

Recent empirical research underscores the heterogeneous nature of these interactions across countries and development stages. For example, Khan et al. (2022) demonstrated that the adoption of renewable energy sources and advanced logistical infrastructure could contribute significantly to low-carbon transitions in emerging economies [12]. Similarly, Ding et al. (2021) highlighted the importance of eco-innovation and energy productivity in reducing consumption-based emissions in developed countries [13]. However, in many OPEC countries, renewable energy still represents a small share of the total energy mix, and institutional capacities for green finance are evolving rather slowly [14, 15].

In the Middle Eastern and North African (MENA) context, several studies have addressed the relationship between trade, financial development, and emissions. Omri and Kahouli (2016), using a dynamic simultaneous-equation model, found bidirectional causality between financial development and energy consumption in MENA countries, implying that financial systems can both drive and respond to changes in energy use [6]. Likewise, Omri et al. (2015) observed that while trade and financial openness contribute to economic growth, their effects on CO_2 emissions are contingent upon regulatory quality and energy structure [16]. These findings reinforce the need for contextualized analyses in countries like those of OPEC, where energy markets are tightly interwoven with state-led economic models.

Iran offers a compelling case study in this regard. As noted by Shahnazi et al. (2017), energy consumption in various economic sectors in Iran has shown a strong association with carbon emissions and economic expansion, driven largely by fossil fuel subsidies and insufficient regulatory frameworks [17]. Kouyakhi et al. (2021) further dissected Iran's electricity sector and found ownership structure and sectoral policy distortions to be key drivers of emissions [18]. Similarly, Sharzehi and Haghani (2010) emphasized the importance of causality between national income and CO_2 emissions, emphasizing the role of energy consumption in Iran's emission trajectory [19]. These insights call for a sector-specific and institutional lens when assessing financial development's environmental impact in OPEC nations.

Moreover, renewable energy financing remains a structural bottleneck in many oil-dependent economies. While Farahti et al. (2024) emphasized the potential for targeted financial instruments in supporting clean energy investments in developing countries, they also acknowledged institutional inertia and limited investor confidence as major constraints [8]. This aligns with findings from Ghallabi et al. (2025), who utilized advanced machine learning models to predict clean energy price movements and ESG market responses, underscoring the importance of financial markets in clean energy transitions [14].

Urbanization and affluence are also contributing to rising energy demands in many OPEC member states. Shahbaz et al. (2015) revealed that in Malaysia, urban expansion and trade openness were positively correlated with increased energy consumption, further straining environmental resources [20]. These insights are transferable to many OPEC nations, where rapid urbanization is not always accompanied by sustainable planning. Likewise, Saidi and Mbarek (2016) found that urbanization and financial development significantly contribute to CO_2 emissions in emerging economies, signaling a need for integrated urban-financial-environmental policies [5].

While macroeconomic stabilization policies have been widely deployed in developing countries to address environmental degradation, the literature increasingly questions their effectiveness relative to direct environmental regulation. Chan (2020), for instance, used a dynamic stochastic general equilibrium (DSGE) framework to argue that carbon-dependent fiscal and monetary policies may have limited impact on air pollution compared to targeted environmental instruments [21]. Therefore, OPEC countries must consider a suite of policy interventions—financial, regulatory, and infrastructural—to effectively manage the energy-emissions nexus.

The inclusion of trade dynamics in environmental models further enriches the analytical framework. Adebayo et al. (2021) showed that trade openness exerts asymmetric effects on carbon emissions in Sweden, depending on the level of renewable energy adoption [22]. Similarly, Ghazouani et al. (2020) demonstrated in Asia-Pacific countries that renewable electricity consumption, trade openness, and economic growth interact in complex, often non-linear ways [23]. These insights are especially pertinent for OPEC members seeking to leverage trade diversification without undermining their environmental commitments.

In addition, carbon pricing mechanisms such as emissions trading schemes (ETS) have shown varying degrees of success across countries. Hu et al. (2020) found that China's ETS implementation had a favorable impact on emission reductions and energy conservation within the industrial sector [11]. Although few OPEC countries have implemented ETS frameworks, such market-based instruments could potentially be adapted to local contexts as part of broader sustainability strategies.

The growing relevance of low-income and transition economies in the climate discourse has also brought attention to their unique vulnerabilities and opportunities. Ehigiamusoe and Dogan (2022) emphasized the role of income-renewable energy interactions in shaping emissions outcomes in low-income countries, stressing the importance of inclusive energy policies [3]. Meanwhile, Yu et al. (2023) provided robust evidence of the synergistic effects of renewable energy adoption and financial development on environmental sustainability in Asian countries, pointing to the importance of tailored policy mixes [10].

In the context of South and Southeast Asia, studies such as those by Jahangir Alam et al. (2012) and Li et al. (2014) highlighted the bidirectional relationships between energy use, carbon emissions, and economic growth, thereby validating the complexity of the energy-environment-growth triad [24, 25]. As many OPEC countries diversify their economic base and strengthen financial systems, the interdependence between these variables will only deepen.

In sum, the existing literature provides a solid foundation for exploring the triadic relationship between financial development, energy consumption, and environmental outcomes. However, for OPEC nations, the specificities of resource dependency, institutional structures, urban growth, and energy subsidies necessitate localized empirical inquiry. This study, therefore, contributes to the discourse by empirically analyzing the dynamic relationships among financial development, carbon emissions, and energy consumption in OPEC countries during the period 2013–2024, using robust panel econometric methods.

2. Methodology

The Generalized Method of Moments (GMM) is a powerful estimation technique for dynamic panel models, addressing issues such as the presence of country-specific fixed effects, endogeneity of variables, and lagged dependent variables. To estimate the model using this method, the instrumental variables employed in the model must first be identified. The consistency of the GMM estimator depends on the validity of the instruments. This validity can be tested using the specification test introduced by Arellano and Bond (1991). The Sargan test is used to assess the validity of the instruments. Failure to reject the null hypothesis in this test provides evidence in support of the instruments' validity.

The Dynamic Ordinary Least Squares (DOLS) method is an econometric technique used to estimate the long-run relationship among variables in the presence of variables integrated of order one (I(1)) and challenges such as cointegration and endogeneity. This method was introduced by Stock and Watson (1993) and is particularly applicable in time-series and panel data analyses. Given the long-run cointegrated relationship among the variables, the model can be estimated using the DOLS method. The panel DOLS estimator is expressed as follows:

$\hat{\beta}_{GD}^* = [N^{-1} * (\sum_{t=1}^{T} z_{it} z_{it}')^{-1} * (\sum_{t=1}^{T} z_{it} \tilde{S}_{it})] + \varepsilon_{it}^*$

where z_{it} is a $2(K+1)\times1$ regressor vector, and $\tilde{S}_{it} = S_{it} - \bar{S}_{it}$,
$Z_{it} = (X_{it} - \bar{X}_i, \Delta X_{(it-K)}, \ldots, \Delta X_{(it+K)})$

In the conventional panel DOLS estimator, the sum across cross-sections in the first equation is identical. Thus, the panel DOLS estimator can be rewritten as $\hat{\beta}_{GD}^* = N^{-1} \sum_{i=1}^{N} \beta_{(D,i)}^*$ where $\beta_{(D,i)}^*$ is the conventional panel DOLS estimator defined by the following equation (Sadeghi & Eslami, 2011):

$t\beta_{GD}^* = N^{-1/2} \sum_{i=1}^{N} t\beta_{(D,i)}^{\wedge}$,
$t\beta_{(D,i)}^{\wedge} = (\beta_{(D,i)}^* - \beta) * (\hat{\sigma}_i^{-2} \sum_{t=1}^{T} (X_{it} - \bar{X}_i)^2)^{1/2}$ (

4. Model Estimation

Based on the proposed model and the defined variables, this section comprehensively analyzes appropriate estimation methods and interprets the results:

$LCO_{it} = \beta_{0i} + \beta_{1i} LCO_{it-1} + \beta_{2i} LGDP_{it} + \beta_{3i} (LGDP)^2_{it} + \beta_{4i} FD_{it} + \beta_{5i} LENERGY_{it} + U_{it}$

The proposed model is a dynamic panel model that examines the relationship between environmental pollution (the dependent variable) and economic growth, energy consumption, and financial development. The components of the model and the estimation method are analyzed below:

1. Model Variables and Their Interpretation:

- LCO_{it}: Logarithm of carbon dioxide emissions (a proxy for environmental pollution) for country *i* in year *t*.
- LCO_{it-1}: One-year lag of the dependent variable, indicating the persistence of pollution and its influence from the previous period.
- $LGDP_{it}$: Logarithm of real per capita GDP (economic growth).
- $(LGDP)^2_{it}$: Squared logarithm of real per capita GDP, used to assess the nonlinear relationship (Environmental Kuznets Curve hypothesis).
- FD_{it}: Financial development index (domestic credit to the private sector as a percentage of GDP).

- *LENERGY_it*: Logarithm of per capita energy consumption (energy as a primary contributor to pollution).

2. Model Hypotheses:

The linear and quadratic relationships between GDP and pollution (LCO) are used to test the Environmental Kuznets Curve (EKC) hypothesis. If:

- $\beta_2 > 0$ and $\beta_3 < 0$: the relationship is inverted U-shaped (pollution increases at low levels of economic growth but decreases after a turning point).
- $\beta_2 < 0$ and $\beta_3 > 0$: the relationship is U-shaped.

Financial development (FD) and energy consumption (LENERGY) are also considered as key control variables.

Due to the dynamic nature of the model, the presence of the lagged dependent variable among the independent variables, and the persistence of pollution that carries over from one period to another, the Generalized Method of Moments (GMM) is employed for estimation. The estimation results are obtained using *Stata 14* software.

3. Findings and Results

This section first reports the results of the Arellano and Bond dynamic panel estimation (GMM) and then proceeds to interpret the models.

Table 1. Estimation Results of Arellano and Bond Dynamic Panel GMM

Parameter	Coefficient	Standard Error	Z-Statistic	P > Z
LCO_t−1	0.50	0.04	10.80	0.00
LENERGY	0.44	0.04	10.01	0.00
LFD	0.05	0.03	1.73	0.08
LGDP	0.09	0.03	3.24	0.00
(LGDP)^2	-1.52	5.76	-2.63	0.00

At the 90% confidence level, all variables become statistically significant. The model estimation results show that the coefficient for energy consumption is approximately 0.44. This implies that a 1% increase in energy consumption in the studied countries leads to a 0.44% increase in CO_2 emissions. The coefficient for GDP is 0.09, indicating that a 1% increase in GDP results in a 0.09% increase in CO_2 emissions. Conversely, the coefficient for the squared GDP is -1.52, which, as expected, is negative and aligns with the assumptions of the Environmental Kuznets Curve (EKC) hypothesis. This confirms the concave (inverted U-shaped) form of the EKC and indicates that with further economic growth, an inverse relationship between GDP and CO_2 emissions begins. In this study, this result is statistically significant, providing support for the EKC hypothesis. These results are statistically significant at the 10% critical level.

Table 2. Sargan Test Results

Statistic	Prob Value
157.69	0.40

Since the p-value of the Sargan test is above 5%, the null hypothesis that the instruments are valid cannot be rejected.

Table 3. Wald Test Results

Statistic	Prob Value
114.10	0.00

The Wald test indicates the overall significance of the regression. Since the p-value is less than 5%, the regression as a whole is statistically significant.

The proposed model is as follows:

LCO_it = β_0i + β_1i LGDP_it + β_2i (LGDP)^2_it + β_3i FD_it + β_4i LENERGY_it + β_5i LURBAN_it + U_it

Variables and Definitions:

- **Dependent Variable:**
  - *LCO*: Logarithm of CO_2 emissions (environmental pollution indicator)
- **Main Independent Variables:**
  - *LGDP*: Logarithm of real per capita GDP (economic growth)
  - *(LGDP)^2*: Squared LGDP (to test the Environmental Kuznets Curve)
- **Control Variables:**
  - *FD*: Logarithm of financial development (credit to the private sector as a percentage of GDP)
  - *LENERGY*: Logarithm of per capita energy consumption
  - *LURBAN*: Logarithm of urbanization rate
- **Data:**
  - *Time Period*: 1992–2013 (22 years)
  - *Countries*: 12 OPEC member countries
  - *Data Source*: World Bank

The time frame of this study spans from 2013 to 2023. The countries under investigation are OPEC member states, including: Angola, Ecuador, Nigeria, Libya, Iraq, Iran, United Arab Emirates, Saudi Arabia, Venezuela, Algeria, Qatar, and Kuwait. All necessary data for this study were collected from the World Bank database.

Table 4. Panel Unit Root Test Results for Research Variables

Variable	Panel Unit Root Tests	Level	First Difference	Result
LGDP	LLC	*1.31** (0.90)	*–21.47** (0.00)	I(1)
	IPS	3.56 (0.99)	–9.04 (0.00)	I(1)
	ADF	10.37 (0.99)	314.29 (0.00)	I(1)
LENERGY	LLC	2.08 (0.98)	–4.64 (0.00)	I(1)
	IPS	4.94 (1.00)	–6.26 (0.00)	I(1)
	ADF	6.16 (0.99)	83.74 (0.00)	I(1)
LFD	LLC	–0.37 (0.35)	–5.59 (0.00)	I(1)
	IPS	–0.90 (0.81)	–5.88 (0.00)	I(1)
	ADF	22.95 (0.52)	–79.41 (0.00)	I(1)
LURBAN	LLC	–16.68 (0.00)	–	I(0)
	IPS	–2.94 (0.00)	–	I(0)
	ADF	282.94 (0.00)	–	I(0)
LCO	LLC	*0.55** (0.71)	*–9.40** (0.00)	I(1)
	IPS	1.45 (0.92)	–9.90 (0.00)	I(1)
	ADF	14.57 (0.93)	183.60 (0.00)	I(1)
LTRADE	LLC	–0.79 (0.21)	–7.37 (0.00)	I(1)
	IPS	–0.04 (0.48)	–6.71 (0.00)	I(1)
	ADF	27.33 (0.28)	89.20 (0.00)	I(1)

*Note: * refers to the test statistic value, and ** refers to the p-value.*

Since the variables are a mix of stationary and non-stationary, the Kao and Pedroni cointegration tests are used to avoid spurious regression.

Table 5. Kao Cointegration Test

Test Statistic	Prob
–3.93	0.00

The obtained p-value indicates that the null hypothesis cannot be rejected, suggesting the existence of cointegration and a long-run relationship among the model variables. To determine the long-run relationship among the variables, Pedroni proposes seven cointegration tests, categorized into two main groups.

Table 6. Pedroni Panel Cointegration Test Results

Intra-Group Statistics	Unweighted	Weighted
Panel v-statistic	*–1.38** (0.91)	*–0.94** (0.82)
Panel rho-statistic	0.87 (0.80)	1.13 (0.87)
Panel PP-statistic	–3.70 (0.00)	–3.94 (0.00)
Panel ADF-statistic	–1.14 (0.12)	–2.68 (0.00)
Inter-Group Statistics		
Group rho-statistic	2.49 (0.99)	
Group PP-statistic	–4.52 (0.00)	
Group ADF-statistic	–1.02 (0.15)	

** refers to the test statistic value, and ** refers to the p-value.*

From the results in Table 6, it can be concluded that there is a cointegration relationship specified in the model. After the panel cointegration tests reported a significant cointegration relationship, the FMOLS method is employed using EViews 9 to estimate the long-run coefficients.

Table 7. Dynamic Panel Estimation Using FMOLS Method

Parameter	Coefficient	Standard Error	Z-Statistic	P > Z
LENERGY	0.79	0.04	8.99	0.00
LFD	0.09	0.05	1.86	0.06
LGDP	0.29	0.11	2.54	0.01
(LGDP)^2	–2.84	1.10	–2.56	0.01
LURBAN	0.11	0.06	1.75	0.08

$R^2 = 0.96$

Using the FMOLS method, a 1% increase in energy consumption results in a 0.79% increase in CO_2 emissions. Additionally, a 1% increase in financial development leads to a 0.09% increase in CO_2 emissions, while a 1% increase in urbanization leads to a 0.11% increase in CO_2 emissions. Furthermore, a 1% increase in GDP results in a 0.29% increase in carbon emissions.

4. Discussion and Conclusion

The empirical findings of this study provide significant insight into the dynamic interplay between financial development, energy consumption, and carbon emissions in OPEC member countries over the period 2013–2024. Using the Generalized Method of Moments (GMM) and Fully Modified Ordinary Least Squares (FMOLS) estimators, the analysis revealed several key relationships. Notably, energy consumption had a strong and statistically significant positive effect on carbon emissions, with a 1% increase in energy consumption leading to a 0.79% increase in CO_2 emissions. This result aligns with the established understanding that energy consumption—particularly in fossil-fuel-dependent economies such as those of OPEC—is a major contributor to environmental degradation [17, 18]. The finding confirms that current energy profiles in these nations remain highly carbon-intensive and that energy policy reform remains a critical element of climate strategy.

Similarly, the results indicate that financial development positively influences carbon emissions, albeit with a smaller magnitude. A 1% increase in financial development was associated with a 0.09% rise in carbon emissions. This finding supports the dual-natured role of financial development, where expanded financial resources may stimulate economic activities, including those in carbon-intensive sectors, without necessarily translating into green investment unless guided by stringent environmental policy frameworks [5, 7, 10]. While financial development holds promise for promoting sustainability, the lack of alignment with environmental criteria and green finance incentives appears to hinder its effectiveness in the OPEC context.

The EKC hypothesis was validated in this study through the significance and expected signs of both GDP and squared GDP terms. Specifically, the positive coefficient of GDP and the negative coefficient of squared GDP confirm the inverted U-shaped relationship between income and emissions, which implies that as countries grow richer, emissions initially rise and then decline after surpassing a certain income threshold [1-3]. This result suggests that several OPEC economies may be transitioning into the second phase of the EKC, where structural transformation and increased environmental awareness begin to reduce emission intensity. However, such outcomes depend heavily on institutional reforms, technological upgrading, and regulatory enforcement—areas where many OPEC countries still face challenges.

Urbanization also emerged as a significant explanatory variable in the FMOLS model, with a positive coefficient indicating that increases in urban population are associated with higher levels of carbon emissions. A 1% increase in urbanization results in a 0.11% increase in emissions. This finding corresponds with the broader literature that associates rapid urban growth in developing countries with increased energy demand, vehicular emissions, construction activity, and industrial expansion [5, 20]. For OPEC countries, where urbanization is often characterized by unregulated expansion and limited public transportation infrastructure, this result emphasizes the importance of sustainable urban planning and investment in low-carbon urban services.

The results from the Kao and Pedroni cointegration tests confirmed the existence of a long-run equilibrium relationship between the variables in the model, reinforcing the argument that economic development, energy policy, and financial systems are structurally interlinked. These tests validate the use of FMOLS to estimate long-term coefficients and further corroborate the relevance of including financial development and urbanization alongside traditional variables in environmental modeling. This methodological robustness strengthens the credibility of the study's conclusions.

These findings are consistent with the results of several prior empirical investigations. For example, Hu et al. (2020) found that China’s carbon emission trading scheme (ETS) had a positive impact on energy conservation and emission reduction in the industrial sector, suggesting that market mechanisms—when well-implemented—can mitigate the negative externalities of financial and industrial expansion [11]. Yet, the lack of comparable mechanisms in OPEC countries implies that financial development alone may not yield environmental dividends unless explicitly steered toward low-carbon investments [8, 14]. The findings also echo those of Omri and Kahouli (2016), who established bidirectional causality between financial development and energy consumption in MENA countries, highlighting the feedback loop between economic and energy systems [6].

Trade openness, although not included in the main regression due to data limitations in this version of the model, has been found in previous studies to exert an ambiguous effect on carbon emissions. For instance, Adebayo et al. (2021) identified that the impact of trade openness on emissions depends significantly on the level of renewable energy adoption, with cleaner energy mitigating the harmful effects of trade on the environment [22]. Ghazouani et al. (2020) reached similar conclusions in the Asia-Pacific context, suggesting that the environmental impact of trade is heavily context-dependent and conditional on institutional and energy market characteristics [23]. Thus, future models could be enhanced by incorporating trade variables and interaction terms to better capture these dynamics.

Notably, the study also contributes to the growing discourse on the policy mechanisms necessary to reconcile financial development with climate goals. Xie and Lin (2025) illustrated how financial leasing can shape the investment behavior of renewable energy firms, particularly in the context of changing government subsidy regimes [9]. Zhang et al. (2023) also emphasized the utility of asset securitization in financing renewable energy enterprises in China, indicating that innovation in financial instruments can help overcome capital constraints in clean energy transitions [15]. These insights are particularly relevant for oil-exporting nations that are exploring economic diversification pathways and seeking to attract private capital for renewable infrastructure.

In a similar vein, Khan et al. (2022) emphasized the importance of logistical infrastructure and low-carbon initiatives in promoting integrated global sustainability [12]. Their findings underscore the interconnectedness of supply chains, energy systems, and finance in shaping environmental outcomes. As OPEC countries continue to engage with global markets and international climate frameworks, the alignment of financial development with green industrial strategy will be essential.

The policy relevance of the findings cannot be overstated. With financial development exhibiting a positive but moderate impact on emissions, there is an opportunity to redirect capital flows toward climate-friendly sectors. Yu et al. (2023) and Ding et al. (2021) have both emphasized the importance of financial institutions, market incentives, and regulatory clarity in driving sustainable production and energy use [10, 13]. The results of the current study suggest that without targeted policies—such as green bonds, tax incentives for clean energy, and ESG reporting standards—the full environmental benefits of financial development may remain unrealized in OPEC nations.

Despite the robust methodology and comprehensive dataset, this study has several limitations. First, the model primarily includes macro-level variables and may not fully capture sectoral heterogeneity within OPEC economies, especially variations between energy-intensive and service-oriented sectors. Second, while the time period (2013–2024) offers a recent perspective, it may not fully reflect long-term structural transformations, particularly in countries experiencing rapid institutional change or political instability. Third, this analysis does not explicitly include technological innovation or environmental policy stringency due to data constraints, which may affect the interpretation of financial development's impact on emissions.

Future studies can enhance this work by incorporating sector-specific data, especially on the industrial, residential, and transportation sectors, which are major contributors to carbon emissions. Including variables related to institutional quality, technological innovation, and climate policies would also improve model accuracy and explanatory power. Moreover, comparative studies between OPEC and non-OPEC developing countries would provide broader insights into how resource dependence shapes the energy-finance-environment nexus. Additionally, nonlinear techniques and machine learning models could uncover hidden patterns and threshold effects not captured by traditional econometric methods.

To ensure sustainable development, policymakers in OPEC countries must integrate environmental objectives into financial planning and regulation. This involves designing fiscal instruments that channel credit and investment toward low-carbon industries, developing green capital markets, and mandating ESG disclosure frameworks. Urban planning should be aligned with sustainability principles to reduce the carbon footprint of growing cities. Lastly, capacity building in financial institutions for green finance assessment and monitoring is essential to unlock the transformative potential of financial development for environmental sustainability.

Authors' Contributions

Authors equally contributed to this article.

Ethical Considerations

All procedures performed in this study were under the ethical standards.

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Conflict of Interest

The authors report no conflict of interest.

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References

[1] T. Li and Y. A. U. Z. D. Wang, "Environmental Kuznets Curve in China: New Evidence From Dynamic Panel Analysis," *Energy Policy,* vol. 91, pp. 138-147DO - 10.1016/j.enpol.2016.01.002, 2016.

[2] M. Shahbaz, M. K. Mahalik, S. H. Shah, and J. R. Sato, "Time-varying analysis of CO2 emissions, energy consumption, and economic growth nexus: Statistical experience in next 11 countries," *Energy Policy,* vol. 98, pp. 33-48, 2016/11/01/ 2016, doi: 10.1016/j.enpol.2016.08.011.

[3] K. U. Ehigiamusoe and E. Dogan, "The role of interaction effect between renewable energy consumption and real income in carbon emissions: evidence from low-income countries," *Renewable and Sustainable Energy Reviews,* vol. 154, p. 111883, 2022, doi: 10.1016/j.rser.2021.111883.

[4] K. H. Nguyen and M. Kakinaka, "Renewable energy consumption, carbon emissions, and development stages: Some evidence from panel cointegration analysis," *Renewable Energy,* vol. 132, pp. 1049-1057, 2019. [Online]. Available: https://doi.org/10.1016/j.renene.2018.08.069.

[5] K. Saidi and M. B. Mbarek, "The impact of income, Trade, Urbanization and Financial Development on Co2 Emission in 19 Emerging Economies," *Environ Sci Pollut Res,* vol. 60, pp. 60-75, 2016, doi: 10.1007/s11356-016-6303-3.

[6] A. Omri and B. Kahouli, "Causal Relationships Between energy consumption, Forign Direct Investment and Economic Growth: Fresh Evidence From Dynamic Simultaneous- Equations Models," *Energy Policy,* 2016, doi: 10.2139/ssrn.2643721.

[7] A. Rehman, Z. Batool, Q. U. Ain, and H. Ma, "The renewable energy challenge in developing economies: An investigation of environmental taxation, financial development, and political stability," *Natural Resources Forum,* vol. 49, no. 1, pp. 699-724, 2025, doi: 10.1111/1477-8947.12418.

[8] M. Farahti, L. Salimi, and M. Gholizadeh Arat Bani, "Financing Renewable Energy Projects: A Case Study of Selected Developing Countries," *Iranian Journal of Energy Economics,* 2024, doi: 10.22054/jiee.2024.76012.2042.

[9] Y. Xie and B. Lin, "Financial leasing and China's renewable energy firms' investment behavior: In the context of government subsidy reduction," *Renewable and Sustainable Energy Reviews,* vol. 214, p. 115547, 2025.

[10] H. Yu, R. Nazir, J. Huang, and H. Li, "Linkages between renewable energy, financial development, and environmental sustainability in Asian countries," *Economic Research-Ekonomska Istraživanja,* vol. 36, no. 3, p. 2192764, 2023, doi: 10.1080/1331677X.2023.2192764.

[11] Y. Hu, S. Ren, Y. Wang, and X. Chen, "Can carbon emission trading scheme achieve energy conservation and emission reduction? Evidence from the industrial sector in China," *Energy Economics,* vol. 85, p. 104590, 2020/01/01/ 2020, doi: 10.1016/j.eneco.2019.104590.

[12] S. A. R. Khan, D. I. Godil, Z. Yu, F. Abbas, and M. A. Shamim, "Adoption of renewable energy sources, low-carbon initiatives, and advanced logistical infrastructure—an step toward integrated global progress," *Sustainable Development*, vol. 30, no. 1, pp. 275-288, 2022, doi: 10.1002/sd.2243.

[13] Q. Ding, S. I. Khattak, and M. Ahmad, "Towards sustainable production and consumption: Assessing the impact of energy productivity and eco-innovation on consumption-based carbon dioxide emissions (CCO2) in G-7 nations," *Sustainable Production and Consumption*, vol. 27, pp. 254-268, 2021/07/01/ 2021. [Online]. Available: https://doi.org/10.1016/j.spc.2020.11.004.

[14] F. Ghallabi, B. Souissi, A. M. Du, and S. Ali, "ESG stock markets and clean energy prices prediction: Insights from advanced machine learning," *International Review of Financial Analysis*, vol. 97, no. 1, p. 103889, 2025, doi: 10.1016/j.irfa.2024.103889.

[15] M. Zhang, Y. Tang, L. Liu, J. Jin, and D. Zhou, "Is asset securitization an effective means of financing China's renewable energy enterprises? A systematic overview," *Energy Reports*, vol. 9, pp. 859-872, 2023, doi: 10.1016/j.egyr.2022.12.032.

[16] A. Omri, S. Daly, A. Chaibi, and C. Rult, "Financial Development, Environmental Quality, Trade and Economic Growth : What Cause What MENA Countries," *Working Paper*, pp. 10-20, 2015, doi: 10.2139/ssrn.2573609 10.2139/ssrn.2575048 10.1016/j.eneco.2015.01.008.

[17] R. Shahnazi, E. Hadiyan, and L. Jorgani, "An Investigation of Energy Consumption, Economic Growth and Co2 Emission in the Iranian Economic Sectors," (in Fa), *Journal of Economic Growth and Development Research*, vol. 7, no. 28, pp. 70-51, 2017. [Online]. Available: https://www.magiran.com/paper/1735385.

[18] N. Kouyakhi, S. Rajabi, and Shavvalpour, "The Driving Forces of Energy Consumption and Carbon Dioxide Emissions in Iran's Electricity Sector: A Decomposition Analysis Based on Types of Ownership," *Cleaner Environmental Systems*, vol. 2, p. 100012, 2021, doi: 10.1016/j.cesys.2021.100012.

[19] G. Sharzehi, Haghani, Majid, "Causality between Co2 Gas Emission and National income with Emphasis on Energy Consumption in IRAN," *Journal of Economic Research (Tahghighat- E- Eghtesadi)*, vol. 44, no. 2, pp. -, 2010. [Online]. Available: https://jte.ut.ac.ir/article_20015_39fe5a02cc81ef8d5f25b45b8f487b4b.pdf.

[20] M. Shahbaz, N. Loganathan, R. Sbia, and T. Afza, "The Effect of Urbanization, Affluence and Trade Openness on Energy Consumption : A Time series Analysis in Malysia," *Renewable and Sustainable Energy Review*, vol. 47, pp. 683-693DO - 10.1016/j.rser.2015.03.044, 2015.

[21] Y. T. Chan, "Are macroeconomic policies better in curbing air pollution than environmental policies? A DSGE approach with carbon-dependent fiscal and monetary policies," *Energy Policy*, vol. 141, p. 111454, 2020/06/01/ 2020, doi: 10.1016/j.enpol.2020.111454.

[22] T. S. Adebayo, H. Rjoub, G. D. Akinsola, and S. D. Oladipupo, "The asymmetric effects of renewable energy consumption and trade openness on carbon emissions in Sweden: new evidence from quantile-on-quantile regression approach," *Environmental Science and Pollution Research*, pp. 1-12, 2021. [Online]. Available: https://doi.org/10.1007/s11356-021-15706-4.

[23] T. Ghazouani, J. Boukhatem, and C. Yan Sam, "Causal interactions between trade openness, renewable electricity consumption, and economic growth in Asia-Pacific countries: Fresh evidence from a bootstrap ARDL approach," *Renewable and Sustainable Energy Reviews*, vol. 133, p. 110094, 2020/11/01/ 2020, doi: 10.1016/j.rser.2020.110094.

[24] M. Jahangir Alam, I. Ara Begum, J. Buysse, and G. Van Huylenbroeck, "Energy consumption, carbon emissions and economic growth nexus in Bangladesh: Cointegration and dynamic causality analysis," *Energy Policy*, vol. 45, pp. 217-225, 2012/06/01/ 2012, doi: 10.1016/j.enpol.2012.02.022.

[25] J. Li, Y. H. Chiang, Z. Lu, and T. N. Choi, "Measuring Carbon Emission From Energy Consumption in a Hong Kong Family," *Facilities*, vol. 32, no. 7/8, pp. 324-341, 2014, doi: 10.1108/f-12-2011-0099.