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Effect of energy consumption, foreign direct investment, and economic growth on greenhouse gas emissions in OPEC member states: evidence from panel data analysis

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Our paper explores the impact of energy consumption, foreign direct investment, and economic expansion on greenhouse gas emissions in OPEC member states. A panel data of 12 out of 13 OPEC nations over the period 1983 to 2022 obtained from the World Development Indicators is used. The autoregressive distributed lag simulation was adopted to determine the correlation among the series. Our estimations unveil that economic growth in the member states contributes 7.47 per cent to greenhouse gas emissions for every 1 percent increase, trade flow tends to reduce greenhouse gas emissions by 0.37 per cent for every 1 percent rise. Though the impact of foreign direct investment on greenhouse gas emissions in the OPEC member states is negative, it is statistically insignificant. The positive association between energy consumption and greenhouse gas emissions emphasizes the need for OPEC countries to move to cleaner energy sources in order to reduce environmental damage. A proactive approach to investing in clean technology is critical for governments and companies in OPEC countries. This includes supporting research and development of renewable energy sources, encouraging the adoption of environmentally-safe practices in industry and fostering innovation to promote sustainable development. Strict environmental standards for industries that contribute significantly to greenhouse gas emissions should be adopted and enforced. This includes: Setting caps on emissions, advocating for cleaner production processes, and imposing penalties for non-compliance with environmental regulations. Sustainable practices should be encouraged through tax incentives, subsidies, and other financial mechanisms designed to incentivized companies to adopt environmentally friendly processes. The implications of these findings for policymakers and future studies are discussed.

KEYWORDS

ARDL bound test, economic growth, energy consumption, environment, FDI, greenhouse gas, OPEC

1 Introduction

GDP growth is strongly associated to carbon emissions, mainly when relied on intensive energy utilization and fossil sources for energy manufacturing (Nutá et al., 2024). The pursuit of economic advancement; a central goal for nations worldwide, has historically been linked with the use of energy resources and industrialization. As countries aim to enhance living standards and the welfare of their citizens, they often look to attract foreign direct investment (FDI) to drive their economies. However, this pursuit of prosperity has come at a cost, particularly in terms of increased greenhouse gas (GHG) emissions. In an era marked by heightened environmental awareness and global commitments to combat climate change, understanding the impact of energy consumption, economic prosperity, and FDI on GHG emissions in organization of the petroleum exporting countries (OPEC) nations becomes a crucial and timely research focus. This paper dives into the complex factors that shape the environmental landscape of OPEC economies. OPEC, comprising 13 member states known for their significant role in the global oil industry, occupies a unique position where energy production, economic development, and environmental sustainability intersect. While their oil and gas resources have driven substantial economic growth, they have also contributed significantly to carbon emissions, raising questions about the sustainability of their development paths.

Environmental deterioration triggered by the emission of GHG is extremely resulting to negative consequences across the globe, both in emerging and developed nations (Teng et al., 2021) and likewise, GHG and carbon dioxide (CO_2) outflows in connection with the consumption of fossil fuels have caused negative impacts on environmental quality, standards and protection (Rehman et al., 2021). Moreover, the emission of CO_2 is an important determinant of climate change, resulting to economic losses and natural disasters (Ardakani and Seyedaliakbar, 2019). The subject has brought meaningful and impactful discussions among leading environmental and energy economists (Osobajo et al., 2020). Globally, the main concern of the environmentalists and policymakers in recent years has been the outrush of GHG due to its negative influence on the weather pattern (Mert et al., 2019; Opoku and Boachie, 2020), global warming and air pollution (Mohsin et al., 2021). As stated by Nawaz et al. (2021), several papers explored the pollution ramifications of non-renewable energy expending on environmental health, which has ever been a subject of academic dispensation (Koçak and Sarkgüneşi, 2018).

In a world grappling with the urgency of addressing climate emergency and the exigency to transition to sustainable, low-carbon economies, the discoveries of this investigation have significant inferences for policymakers, environmental advocates, and industry stakeholders. They offer a critical perspective to assess the sustainability of OPEC economies, providing insights that can guide strategies to balance economic progress with environmental conservation. In an era where global environmental challenges demand decisive action, exploring the intricate correlations between FDI, economic expansion, energy consumption, and GHG emissions in OPEC economies takes on paramount importance. This study embarks on this vital inquiry, contributing essential insights to the ongoing discourse on the path toward a more sustainable and harmonious coexistence of economic prosperity and environmental wellbeing. The core focus of our exploration is to analyze the correspondence between FDI, energy utilization, gross domestic product (GDP) growth, and GHG emissions in OPEC economies. Through comprehensive panel data analysis spanning multiple years, this study aims to uncover empirical evidence that illuminates the intricate interplay of these variables. It seeks to not only understand the direct influence of FDI, GDP expansion, and energy consumption on GHG emissions, but also identify potential trade-offs or synergies between these drivers of development and environmental preservation.

The impact of FDI inflows in relation to GHG emissions has been identified by both previous and present studies with mixed conclusions (see Paul et al., 2021). Kastratović (2019) unveiled a positive outcome of FDI in agriculture on CO_2 emission in emerging economies. It has also been found to enhance energy efficiency and clean energy (Lee, 2013; Khandker et al., 2018). In contrast, Mejia (2022) explored the aftermath of FDI inflow on CO_2 excretions and established it to be detrimental in developing economies. Similar conclusions on carbon and CO_2 pollution triggered by the influx of FDI in developing countries were drawn by Xie et al. (2020). The association among economic expansion, GDP growth and GHG emissions requires urgent attention since global warming is mainly caused by such socioeconomic activities (Chen et al., 2016). Amongst the recent dispensations in economics, is the subject of pollution haven hypothesis (PHH) that examines the position of FDI inflow in host economies (Waqih et al., 2019). Moreover, the promotion of future economic wellbeing and environmental protection through energy security and mitigation of carbon emissions can be realized by the efficient usage of renewable energy resources (Zhang et al., 2023).

1.1 Research objectives

1.1.1 General and specific objectives

Our analysis aims to evaluate the impact of economic prosperity, energy consumption and FDI on GHG emissions for OPEC economies by adopting the autoregressive distributed lag (ARDL) method, providing important insights into current studies. Specifically, our investigation aims to evaluate how consumption of fossil fuels and other energy resources correlates with GHG emissions in OPEC countries. It highlighted whether the capital involved in foreign investments contributes to the increase in CO_2 emissions resulting from industrial activity or leads to better energy efficiency and cleaner technology. Further, it explores whether economic progress is associated with higher GHG emissions due to increased industrial activity and energy consumption. Besides, the complex connection between FDI, energy utilization, GDP growth, and GHG emissions is explored, revealing the nuanced relationships in OPEC economies. Additionally, this study assesses the role of trade flows in reducing GHG emissions and provides policy insinuation for policymakers, environmentalists, and industry stakeholders. Our findings revealed that the growth in consumption of energy resources and economic expansion magnifies GHG emissions whereas, trade flow negatively impacts GHG emissions in OPEC member economies.

1.2 Why OPEC member states

The members of OPEC, consisting of 13 countries known for their important role in the global oil industry, are a unique example of this study for several reasons. First, OPEC countries are heavily dependent on oil and gas production for economic survival. These dependencies are the main contributors to global GHG emissions and are therefore important for studying the environmental impacts of economic activities (Mahmood and Saqib, 2022). Furthermore, understanding this relationship is important because it shows how major economies in global energy markets contribute to environmental degradation. This knowledge can inform international policies and collaborative efforts aimed at mitigating climate change. Second, these countries are among the largest consumers of fossil fuels due to their energy-intensive industrial sectors and the availability of cheap energy resources as mentioned by Mahmood and Saqib (2022). Third, OPEC countries attract significant FDI, especially in the energy sector (Lu et al., 2021; Udeagha and Ngepah, 2023). Investigating how these investments affect GHG emissions will help design strategies to promote sustainable investments. The FDI inflow often comes with technology transfer and capital that can be directed to more sustainable energy projects. Fourth, as signatories to various international environmental agreements, OPEC members are under pressure to reduce carbon emissions. The study of the dynamics of these countries can help shape policies that align economic growth with environmental commitments. This aspect of the research is very important because it focuses on the balance between compliance with international agreements and the pursuit of economic development. The results can serve as a basis for policy recommendations to ensure compliance with international standards and maintain economic stability. Fifthly, the need to make the transition to a low-carbon economy is essential for OPEC countries to sustain it in the long term. This study aims to provide ideas that can help in this transition by showing the impact of economic activities on GHG emissions and suggesting ways to reduce this impact. The transition to a low-carbon economy is not only an environmental necessity but also an economic strategy to combat the volatility of fossil fuel markets and the inevitable global shift toward renewable energy sources.

In conclusion, focusing on OPEC member countries provides a broader understanding of the challenges and opportunities they face in balancing economic growth and environmental sustainability. This study aims to contribute to the ongoing discourse on sustainable development by providing empirical evidence and policy recommendations for these economies. By addressing these unique characteristics of OPEC countries, this study aims to provide actionable insights to help these countries accelerate the twin goals of economic development and environmental management.

1.3 Background of the study

In the past, the search for economic development, a priority for nations worldwide, was linked to the use of energy resources and industrialization. Countries aim to improve the lives and wellbeing of their citizens, so they often attract FDI to grow their economies. However, this pursuit of sustainability comes at a high cost, especially in terms of increased GHG emissions as mentioned by Wang and Taghvaee (2023). In an era of growing environmental awareness and global efforts to combat climate change, it is important to understand the impact of energy consumption, economic wellbeing and FDI on GHG emissions in OPEC as a relevant research topic. This study contributes to the ongoing debate on how to coexist with sustainable economic and environmental sustainability by providing empirical evidence on the relationships between FDI, energy use, GDP growth, and GHG emissions in the context of OPEC countries. This evidence fills a gap in the literature where such detailed, region-specific studies are limited. This study shows the trade-offs between the drivers of development and environmental protection, providing a better perspective on how economic policies can be made to reduce negative environmental impacts. The results can guide strategies to achieve sustainable development in OPEC economies by showing the complex relationships between the variables studied, which is especially important due to OPEC's large contribution to global GHG emissions.

This study appears because it addresses an important gap in the literature on the environmental impacts of economic activities in OPEC member states. A sound methodology focused on a specific but globally important group of countries, and useful policy recommendations will contribute to academic research and policy-making in the fields of sustainable development and climate change mitigation. Besides, unlike other studies, which have many broad geographic areas, this study focuses on OPEC member countries. This lens allows for a better understanding of the unique economic and environmental dynamics at play in these oil-rich countries. By examining the specific context of OPEC countries, this study can provide practical and actionable insights that are relevant to unique circumstances. Our investigation uses panel data analysis over several years, which allows us to examine long-term trends and identify causal relationships between variables. This method differs from cross-sectional or short-term studies, which provide a deeper understanding of ongoing effects and dynamics that evolve over time. The use of longitudinal data increases the robustness of our findings and helps demonstrate the effects of immediate and long-term economic activity on GHG emissions. The adoption of the ARDL technique better suits the characteristics of the data and can examine both short-term and long-term dynamics. This approach differs from other studies that may use simpler linear regression models or other econometric methods. The ability of the ARDL method to model dynamic relationships shows how one variable changes in relation to other variables over time, providing a greater understanding of economic and environmental interactions in OPEC countries. By including trade flows in the analysis, this study provides insight into the impact of international trade on GHG emissions in OPEC countries.

These findings are unique and add depth to our understanding of how economic activities other than FDI and investment affect environmental outcomes. Considering trade flows recognizes the globalization of economic transactions and their impact on the environment and demonstrates the importance of the global sector in sustainable development strategies. This study goes

beyond a simple academic analysis and presents policy implications for OPEC countries. These recommendations are designed to help policymakers balance economic growth with environmental sustainability, an area that may not be adequately explored in other studies. By providing practical ideas and strategies, this study aims to bridge the gap between theoretical findings and practical applications and support OPEC countries' efforts to achieve sustainable development goals.

OPEC, a 13-member state known for its important role in the global oil industry, is independent in the area of energy production, economic development, and environmental sustainability. Therefore, the oil and gas resources provide significant economic growth but also contribute significantly to carbon emissions, raising questions about the sustainability of development pathways. The main focus of this study is on OPEC countries, which play an important role in global energy markets and have unique environmental and economic conditions. The novelty of this study comes from its comprehensive analysis of the interactions between FDI, energy consumption, GDP growth, and GHG emissions, especially in OPEC countries. This specific approach is important because environmental policies and economic strategies affect global levels of greenhouse gases due to these countries' reliance on fossil fuel production and export. By identifying specific challenges and opportunities in OPEC member countries, this study provides an important contribution to the broader debate on sustainable development and climate change mitigation.

1.4 Limitations of the study

Acknowledging the limitations of the study is necessary to create a balanced perspective and guide future research. In this study, several factors could affect the robustness and applicability of the findings.

First, variables of interest such as GHG emissions, energy utilization and FDI may contain measurement errors due to differences in their recording and reporting across countries. This can introduce noise into the data, which can lead to inaccurate estimates of the relationships between variables. To mitigate this, the use of robust statistical methods can help reduce the impact of measurement errors. However, some uncertainty always remains due to the inherent limitations of the data. Second, variable selection and model specifications may not capture all relevant factors affecting GHG emissions. If important determinants are not included in the analysis, variable bias may be omitted, leading to biased and inconsistent estimates. An extensive literature review and expert consultations are carried out to ensure a comprehensive model. Despite these efforts, it might be difficult to consider all possible factors influencing the results.

Third, establishing causality in observational studies is inherently difficult. Endogeneity issues, such as the reverse causality between economic growth and greenhouse gas emissions, may influence the results. The study uses methods such as the ARDL approach to address some of the endogeneity problems. However, causal interpretations should be made with caution, as these methods cannot completely exclude the possibility of biased results due to endogeneity. Fourth, the study focuses exclusively on OPEC countries, which have a unique economic and environmental context. OPEC member countries display a wide range of diversity, including size, population, GDP, and GDP per capita. This diversity is important when considering the impact and scope of the findings on OPEC. Besides, OPEC members include countries with large territories, such as Saudi Arabia, and small countries, such as Qatar. The population also varies, from over 200 million in Nigeria to approximately 4 million in Kuwait (Wang and Huang, 2022). The economic output and living standards of OPEC countries are equally disparate. For example, Saudi Arabia has a large GDP due to its large oil reserves and economic activity, while countries such as Venezuela suffer from economic challenges despite having large oil resources. GDP per capita also varies, with high-income countries such as Qatar and low-income countries such as Nigeria in the same organization (Wang and Huang, 2022). The results may not apply to non-OPEC countries or different country groups. The specific dynamics observed in OPEC countries may limit the applicability of the results to other contexts. However, clearly articulating the context-specificity of the findings helps manage expectations about the generalizability of the study's conclusions.

Finally, while the study provides actionable policy recommendations, the implementation of these policies in OPEC member states may be influenced by political, economic and social factors beyond the scope of the study. The effectiveness of recommended policies can be hampered by practical implementation challenges that limit their actual impact. A detailed discussion of potential implementation challenges and proposals to address them can increase the practical relevance of policy recommendations. In conclusion, although this study aims to contribute significantly to the understanding of the relationship between economic growth, energy consumption, FDI, trade flows and GHG emissions in OPEC nations, it is important to acknowledge these limitations. Recognizing these limitations helps contextualize the findings and sets the stage for future research to build on and address these gaps. Unquestionably, the findings from the study will meaningfully contribute to the existing literature given that no other investigations were conducted in line with the variables used in our exploration in the context of OPEC members states. Section 2 presents the theoretical framework, followed by the methodological approach. The estimations are encapsulated in Section 4, while the conclusion and policy implications are enveloped in Section 6.

2 Literature review

2.1 Theoretical and conceptual framework

Addressing the perennial environmental issues and ensuring development sustainability, the proffering and consumption of renewable energy resources, Fan and Hao (2020) applied the vector error correction model (VECM) to study the correlation amongst GDP growth, renewable energy consumption and the influx of FDI for 31 provinces in China. The estimation results revealed a steady equilibrium and long-run interaction among the series. Grabara et al. (2021) applied the Granger Causality and Johansen Co-integration test methods to unveil the correlations between

economic output, renewable energy consumption and the inflow of FDI in Kazakhstan and Uzbekistan. According to the study outcome, the use of electricity and economic expansion were identified as the determinants of renewable energy consumption in both countries. Sarkodie and Strezov (2019) evaluated the effect of economic advancement, energy expenditure and FDI inflows on GHG emissions for South Africa, Indonesia, India, Iran, and China; countries considered as the "top five emitters of greenhouse gases from fuel combustion in the developing countries." The research outcome unveiled positive effects of energy expending on greenhouse gas emissions.

Muhammad et al. (2021) examined the effect of renewable energy consumption, FDI inflow, GDP growth and natural resource endowment on global environmental deterioration over the period 1991–2018. With the exception of the developed economies, the empirical findings unveiled the positive role of FDI inflow in Brazil, Russia, India, China, and South Africa (BRICS) and developing countries. The renewable energy consumption and fuel resources were pinpointed by the authors as the mitigating factors of environmental hazards. Lee (2013) studied the role FDI inflow on clean energy utilization, CO_2 outflows and economic reform. The cointegration tests and fixed effects models were applied for the estimations. The study outcome suggests that the inflow of FDI leads to economic progress and increase energy consumption with no connection to CO_2 outflows. Salahuddin et al. (2018) utilized ARDL technique and VECM to study the role of FDI, energy expenditure, financial development and economic expansion on CO_2 outflows in Kuwait. Their investigations revealed that the variables under study pose a threat to sustainable environment by augmenting carbon emissions.

Rahaman et al. (2022) applied several tests and econometric estimations to determine the role of electricity expedition, FDI inflow, tourism, and economic output on CO_2 outrush in Bangladesh. With the exception of tourism, the examined series have been uncovered to have a "long-run significant impact" on CO_2 outflows. Tang and Tan (2015) adopted the Johansen Co-integration and Granger Causality methods to analyze the associations between energy expenditure, CO_2 outflows, income, and FDI inflow in Vietnam. Energy consumption, FDI inflow and income were uncovered as major stimulants of CO_2 emissions in Vietnam. Kim (2019) utilized the panel VECM to evaluate the correlations among energy utilization, CO_2 excretions, FDI inflow and GDP growth for 57 emerging economies. Empirical findings disclosed that FDI inflow does not affect CO_2 emissions among the selected countries. Hanif et al. (2019) adopted the ARDL technique to survey the effects of GDP expansion, fossil fuel expending, and FDI inflow on CO_2 outflows for a selected number of Asian economies. According to the study outcome, energy consumption and economic wellbeing have enhanced CO2 emissions and environmental degradation regionally, while FDI inflow increased CO_2 emissions domestically.

Gas and oil exploration, industrial and economic activities from top oil-producing and exporting economies also lead to environmental pollution through the emissions of carbon. Ostic et al. (2022) used the generalized methods of moments (GMM) estimators and fully modified least squares (FMOLS) to assess the interrelationship of FDI inflow, economic expansion and import and export of gas and oil for OPEC member states. The investigations confirmed "a positive correlation" linking gas and oil export and CO_2 discharge and between GDP expansion and CO_2 outflows. In contrast, a negative connection between FDI inflows and CO_2 discharge was revealed. Yusuf et al. (2020) adopted the panel ARDL technique to evaluate the connection between energy expending, GDP growth and greenhouse gas emissions in OPEC economies of Africa over the period 1970 to 2016. The analyses disclosed positive influences of GDP growth and energy expenditure on greenhouse gas emissions. Parveen et al. (2021) adopted the Canonical Cointegrating Regression approach to gauge the connection between energy expending, FDI inflow, environmental deterioration and GDP expansion in Pakistan. They suggested that energy utilization has positive correlations with FDI influx, economic expansion, and CO_2 outpouring in Pakistan. Sbia et al. (2014) adopted the vector error correction model, Granger causality and ARDL bounds testing techniques to uncover the associations among FDI inflow, CO_2 emissions and economic wellbeing in the United Arab Emirate (UAE). The study outcome evidenced that FDI inflow, free trade, and CO_2 outflows mitigate energy demand, while clean energy and GDP expansion positively affect energy consumption in the UAE.

Kahia et al. (2019) investigated the aftermath of renewable energy consumption, FDI inflows, and GDP expansion on CO_2 outflows for a number of selected countries across Middle East and North Africa. Their empirical findings unveiled that economic output causes environmental deterioration in those countries. In contrast, FDI inflows, renewable energy consumption and international trade mitigates CO_2 outflows in the region. Udemba et al. (2020) adopted the Pesaran's ARDL approach to uncover the correlations among FDI and tourism inflow, pollutant emission, energy depletion and GDP expansion. With the exception of economic output, a positive connection between pollutant emissions and other series was uncovered. In Korea, Kim (2020) studied and assessed the impacts of GDP growth, urbanization, FDI inflows, industrial structure and renewable energy consumption on GHG emissions. According to the study estimations, economic expansion, FDI inflows, and urbanization were highlighted as the main stimulants of greenhouse gas emissions in Korea over time.

Liobikiene and Butkus (2019) applied the GMM to assess the role of economic wellbeing, FDI inflows, renewable energy consumption and industrialization on GHG emissions. Unlike urbanization and FDI inflow, GDP growth was found to positively and significantly enhance greenhouse gas emissions. Due to technical change in the energy sector, economic wellbeing, trade and urbanization led to the diminution of CO_2 outrush in the selected countries. Mert and Bölük (2016) explored the impact of renewable energy consumption and the influx of FDI on CO_2 emissions in 21 Kyoto nations. Results suggested that the inflow of FDI enhance environmental performance, while renewable energy consumption mitigates CO_2 outflows in these countries. Ben Jebli et al. (2019) investigated the interactions between the influx of tourism, renewable energy consumption, FDI inflow, trade openness, GDP expansion, and CO_2 outflows for 22 states of American economies. Their exploration concluded that renewable energy consumption, tourists and FDI inflow led to the mitigation

of CO_2 outflows, while GDP growth and free trade enhance CO_2 outflows in these countries.

The development of stock markets and influx of FDI have favorably impacted numerous economies across the globe. Paramati et al. (2016) applied the robust panel econometric methods to explore the role and influence of stock markets development and FDI inflow on the consumption of clean energy across 20 developing countries. The research estimations suggested that economic advancement, FDI inflow and market reform positively affect clean energy use. Khan et al. (2019) evaluated the influence of energy utilization, urbanization, economic wellbeing, financial development and socioeconomic globalization on CO_2 outflows in Pakistan. The authors applied the ARDL simulations model for the estimations. With the exception of economic output, innovation and urbanization, findings uncovered a long-run positive influence of the series on CO_2 emissions. Trade, innovation and the inflow of FDI were identified to have negative impact on CO_2 excretion in. Zafar et al. (2020) looked into the interactions among FDI inflow, income, urbanization, energy consumption, education, and their impacts on environmental quality and standards for the Asian economies between 1990 to 2018. The exploration unveiled that the use of energy and income degenerate environmental standards thereby enhancing the emissions of CO_2 in the region.

Salahuddin and Gow (2019) analyzed the aftermath of energy expending, FDI inflow, financial and economic development on sustainable environment in Qatar. The correlations among the series were explored over the period 1980 to 2016. A negative outcome of energy consumption and the influx of FDI on the environment was presented by the findings. Osobajo et al. (2020) adopted the Granger Causality and other econometric estimations methods to evaluate the interactions of GDP expansion and energy utilization on CO_2 outflows for 70 nations from 1994 to 2013. Findings suggest that energy expending and economic output have positive influences on CO_2 outflows in the selected economies. Zhang and Zhou (2016) used "provincial panel data" to evaluate the aftermath of FDI inflow in China and established that the influx of FDI leads to the mitigation of CO_2 outflows in China. Esso and Keho (2016) adopted the Granger Causality and bounds tests to cointegration to check the long-run correlations among economic wellbeing, CO_2 outrush and energy expenditure for 12 Sub-Sahara African economies over the period 1971 to 2010. According to the empirical estimations, economic expansion and energy use were found to enhance atmospheric pollution in most countries.

Besides industrial pollution, the main determinant of environmental pollution [through the emission of greenhouse gases] is the transport energy consumption, particularly in highly populated regions such as China (Jian et al., 2019), India and Pakistan. According to Singh et al. (2008), the Indian transport sector has been considered as the largest consumer of commercial fuel energy. Baloch and Suad (2018) examine the interactions between economic output, transport energy use, urbanization, FDI inflow and the emission of CO_2 from the transport industry in the context of Pakistan over the period 1990 to 2015. The investigations unveiled positive outcomes of transport energy utilization and FDI inflows on CO_2 emissions. Ahmad et al. (2020) adopted the simultaneous equation modeling (SEM) to assess the role of FDI inflow, energy expending, innovation and GDP growth on CO_2 outflows for 24 organization for economic co-operation and development (OECD) member states. Their analyses uncovered that innovation, fossil fuel usage and FDI inflow were the main contributors of CO_2 excretions among the OECD member states. Naz et al. (2019) evaluated the impact of GDP growth, FDI inflows and energy consumption on CO_2 emissions in Pakistan. The study estimations unveiled that the influx of FDI and economic progress enhance CO_2 outflows, unlike renewable energy consumption, which mitigates the emissions over time.

Boohene and Darkwah (2023) investigated the association between CO_2 excretions, energy expending, economic expansion, and FDI inflow from 17 Sub-Saharan African (SSA) countries. They adopted the quantile regression method to analyze these relationships across various quantiles. Concisely, the findings indicate statistically significant effects at specific quantiles, emphasizing the importance of considering these factors at different levels of economic growth. Javed et al. (2023) investigated the influence of various factors, including GDP growth, FDI inflow, energy use, exports, and oil prices on CO_2 in Italy. The study employs yearly time series data spanning from 1971 to 2019 and utilizes the ARDL hypothesis to examine the relationships among variables. They found interconnectedness among the studied series and GDP growth has been unveiled to positively influence carbon outflows, suggesting that economic growth contributes to increased emissions. Andreichyk and Tsvetkov (2023) contributed to the discussion of low-carbon agenda and environmental sustainability within the context of the Shanghai Cooperation Organization (SCO), an international association. The outcome of their study showed that low-carbon agenda and economic expansion are found to be positively connected to greenhouse gas emissions, indicating their significant contributions to higher emissions. Jin et al. (2022) addressed the interconnection between carbon excretion reduction, GDP growth, energy expending and their heterogeneity between developed and developing countries among "the top 28 global carbon-emitting nations," utilizing panel data from the years 2000 to 2017. The study explores co-integration and causality relationships among variables. The research findings uncovered the presence of a two-way causal correlation between GDP growth and carbon outflows across all economies studied, regardless of whether they are developed or developing.

In comparison to the studies conducted in the European Union, Bilalli et al. (2024) adopted panel regression econometric techniques to launched an empirical investigation of how renewable energy consumption, CO_2 emissions, economic progress, and FDI are correlated for Germany, France, Spain, the United Kingdom, Italy, Turkey, Switzerland, the Netherlands, and Poland. Their findings unveiled that renewable energy consumption reduces CO_2 outflows in these European nations, while economic growth has an inverse effect on CO_2 excretions. However, FDI was found to have a positive influence on CO_2 outflows. In Vietnam, Raihan (2024) employed the ARDL method to explore the impact of CO_2 outflows and FDI on Vietnam's GDP growth, using time series data spanning from 1990 to 2021. Based on the study's conclusion, it was discovered that an increase in both CO_2 outflows and FDI result to a long-term gain in economic progress. In the Indian context, Sharmiladevi (2024) utilized the ARDL procedure to examine the

equilibrium correlation among CO_2 excretion, trade liberalization, FDI inflow, and GDP growth. Given the strong cointegration between the series, the author unveiled a significant long-run impacts for GDP growth and trade liberalization and insignificant outcomes with CO_2 outflow and FDI inflow.

2.2 Research gap in the literature

Most studies on the relationship between economic growth, energy consumption, and FDI focus on larger geographic areas or more diverse groups of countries. There is a notable scarcity of research that focuses exclusively on OPEC countries, whose economic and environmental dynamics are driven by their heavy reliance on oil and gas production. The unique relationship between FDI, energy consumption, economic progress, and GHG emissions in OPEC nations has not been fully exploited. This study aims to fill this gap by providing a focused analysis of these variables in the economies of OPEC countries. To address this gap, the study focuses exclusively on OPEC countries and provides a detailed account of how FDI, energy consumption, economic growth and trade flows affect GHG emissions in these economies. In addition, many studies use cross-sectional data or shorter periods that do not adequately reflect long-term trends and relationships. A long-term analysis is needed that can reveal both short and long-term effects, especially in the context of political impacts and economic changes over time. A significant gap in the literature is the lack of comprehensive longitudinal studies on the environmental impact of OPEC countries' economic activities. This study addresses this by using panel data analysis over a long period of time, which provides insight into long-term trends and dynamics. The study uses extended panel data to capture long-term trends and to analyze the relationships between variables.

Although the relationship between economic variables and environmental impacts has been studied using various econometric methods, the application of advanced techniques such as ARDL approach in OPEC countries is still limited. The ARDL method is particularly suitable for studying both short-term and long-term correlations in time-series data. Applying advanced econometric techniques such as ARDL is not sufficient to study the environmental impact of economic activities of OPEC economies. This study fills this gap by using the ARDL method to provide a more robust data analysis. Applying the ARDL approach, the study provides a comprehensive view of both short- and long-term dynamics that improves understanding of causal correlations. Most studies overlook the role of trade flows in influencing GHG emissions, focusing instead on domestic economic activity. Given the significant trade activity of OPEC nations, especially in oil and gas exports, it is important to understand how trade flows affect environmental outcomes. There is limited research on the impact of trade flows on GHG emissions in OPEC economies. This study includes trade flows in the analysis, which provides a more comprehensive view of the factors affecting environmental outcomes. The inclusion of trade flows in the analysis gives a more comprehensive picture of the factors affecting greenhouse gases, which recognizes the important role of international trade in the economies of OPEC member states.

Although these studies provide many theoretical insights, there is still a long way to go in translating these findings into practical policy recommendations that can be applied across all OPEC member states. Policymakers in these countries need practical knowledge to balance economic growth with environmental sustainability. The lack of practical recommendations based on empirical analysis adapted to the context of OPEC nations is a critical gap. This study aims to bridge this gap by providing concrete policy implications that can guide sustainable development in these countries. The research results are translated into actionable policy recommendations that help OPEC policymakers design strategies that balance economic growth with environmental sustainability. The study aims to contribute significantly to the literature on sustainable development and environmental economics by addressing the research gaps. It provides valuable insights into the unique context of OPEC countries and offers both theoretical advances and practical policy recommendations to help these countries meet the challenges of economic advancement and environmental preservation.

3 Methodology

3.1 Data source, symbol, and unit of measurement

Our analysis explores the impact of energy use, economic boom, and FDI inflow on GHG emissions in OPEC member countries by adopting the panel ARDL technique. A panel data of 12 out of 13 OPEC nations over the period 1983 to 2022 obtained from the World Development Indicators (World Development Indicators (WDIs), 2022) is used. Equatorial Guinea, the 13th country was excluded because data for GHG emission and energy consumption variables are missing. This kind of data is most appropriate in addressing familiar issues associated with time series data. It takes care of both the country-specific effects and cross-section heterogeneity across the panels. The paper considers CO_2 as percentage of total fuel combustion, a proxy for greenhouse gas emissions as the outcome variable, while FDI net influx as a portion of GDP, energy use (fossil fuel energy use) as an allotment of total, economic growth (GDP per capita in current US$) as explanatory variables. The study also includes exports of goods and services as an allotment of GDP and total trade as a portion of GDP as control variables. The rationale of including these series is their potential impacts on GHG emissions. The data source, symbol, and unit of measurement are illustrated in Table 1.

The nexus between GHG emissions and macroeconomic series may be examine using a variety of methodologies. To evaluate both the long and short-run aftermath of FDI, energy consumption and economic growth on greenhouse gas emissions, the ARDL bounds methodology of Pesaran et al. (2001) is employed. This methodology is preferred compared to other methods when dealing with independent variables of different order of integration. It also provides more consistent results compared to other techniques when dealing with small sample size (Pesaran et al., 2001). The investigation employs robust estimate methodologies to explore the influence of FDI, energy use, and economic prosperity on GHG emissions. It begins with a complete assessment of the datasets,

which includes size, distribution, measure of central tendency, and variable dispersions. Following that, the paper uses a correlation matrix to investigate probable correlations between variables. This matrix aids in the identification of early associations prior to the application of advanced econometric approaches. Furthermore, the research uses root tests and Pesaran's bounds test to survey the static of variables and autocorrelation in the panel dataset. These evaluations are critical in panel data analysis to avoid spurious regression.

To study the nexus between macroeconomic variables on greenhouse gas emissions, notably the effects FDI, energy use and economic boom on greenhouse gas emissions in 12 OPEC states from 1983 to 2022, a mathematical model can be expressed as given in Equation 1.

$$GHG_{it} = f\,(FDI_{it},\ EC_{it},\ GDPG_{it},\ TRADE_{it}) \tag{1}$$

Equation 1 expresses greenhouse gas emissions of country i over period t as a function of some macroeconomic variables of country i over period t such as foreign direct investment (FDI), energy consumption (EC), gross domestic product (GDPG), and trade (TRADE). Whereas the subscripts (i, t) constitute the cross-section i (member countries) and time t (year) dimension of the panel data. Following Fan and Hao (2020), the statistical specification of the above mathematical equation is presented in Equation 2:

$$GHG_{it} = \beta_0 + \beta_1 FDI_{it} + \beta_2 EC_{it} + \beta_3 lnGDPG_{it} + \beta_4 TRADE_{it} + \alpha_i + \varepsilon_{it} \tag{2}$$

Equation 2 gives an outline of the nexus between GHG emissions and macroeconomic variables. Foreign direct investment (FDI) captures the complex nature of pollution intensive technology and practice on environmental quality (Jiang, 2015). To capture the entire energy usage of a member country, we instead include energy consumption instead of specific energy (Ang, 2007). We also include trade openness in our model to assess the various channel through which openness impact environmental quality (Thuy and Nguyen, 2022). Since all the variables in the model are expressed in percentage except GDPG (GDPG per capita), the study expressed GDP per capita in its natural logarithmic form in order to decrease multicollinearity and eliminate outliers in the panel series (Jiang, 2015). The inclusion of these variables ensures that the essential factors impacting environmental quality are captured in order to provide comprehensive framework for analyzing greenhouse gases; the nexus between GHG emissions and macroeconomic variables. Whereas the β_s measure the percentage changes, α_i is an unobserved cross-sectional unit specific fixed effect and ε is the random disturbance term.

To conduct the Pesaran et al. (2001) bounds testing technique, the study reformulate (Equation 2) into ARDL (p;qk) framework as follows:

$$\Delta GHG_{it} = \alpha_i + \sum_{k=1}^{p} \gamma_1 \Delta GHG_{i,t-k} + \sum_{k=1}^{q} \gamma_2 \Delta FDI_{i,t-k} + \sum_{k=1}^{q} \gamma_3 \Delta EC_{i,t-k} + \sum_{k=1}^{q} \gamma_4 \Delta lnGDPG_{i,t-k} + \sum_{k=1}^{q} \gamma_5 \Delta TRADE_{i,t-k} + \delta_1 GHG_{i,t-1} + \delta_2 FDI_{i,t-1} + \delta_3 EC_{i,t-1} + \delta_4 lnGDPG_{i,t-1} + \delta_5 TRADE_{i,t-1} + \varepsilon_{it} \tag{3}$$

TABLE 1 Data source, symbol, and unit of measurement.

Variables	Symbol	Unit of measurement
Greenhouse gas emission	GHG	CO_2 as percentage of total fuel ignition
Foreign direct investment	FDI	FDI net inflows (% of GDP)
Energy consumption	EC	Fossil fuel energy use (% of total)
Economic growth	GDPG	GDP per capita (current US$)
Trade	TRADE	Trade (% of GDP)

Source: WDIs: https://databank.worldbank.org/source/world-development-indicators.

TABLE 2 Descriptive statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
GHG	480	47.477	12.456	14.112	70.024
FDI	480	1.674	4.85	−18.918	40.167
EC	480	73.942	32.895	15.825	102.788
lnGDPG	480	8.428	1.282	3.129	10.926
TRADE	480	76.347	38.963	−1.405	190.139

Whereas p and q are the lag order for the dependent and independent variables respectively, γ_i on the difference operator (Δ) represents the short run dynamics and δ_s indicate the estimates of the long run cointegration relationship. The significance of the lagged values of the variables is assessed to see whether there is a autocorrelation between the series from Equation 3. Pesaran et al. (2001) suggested a null hypothesis of no cointegration and specified as $H_0 = \delta_1 = \delta_2 = \delta_3 = \delta_4 = \delta_5 = 0$. To integrate the short-run dynamics using the error correction model, the estimates of the long run cointegration relationship in Equation 3 are replaced with the lagged residual of the long run cointegration relationship (ECT_{t-1}) as presented in Equation 4.

$$\Delta GHG_{it} = \alpha_i + \sum_{k=1}^{p} \gamma_1 \Delta GHG_{i,t-k} + \sum_{k=1}^{q} \gamma_2 \Delta FDI_{i,t-k} + \sum_{k=1}^{q} \gamma_3 \Delta EC_{i,t-k} + \sum_{k=1}^{q} \gamma_4 \Delta lnGDPG_{i,t-k} + \sum_{k=1}^{q} \gamma_5 \Delta TRADE_{i,t-k} + \gamma_6 ECT_{i,t-1} + \varepsilon_{it} \tag{4}$$

Where, ECT is the error correction term in the model and is expected predicted to have a negative value for the speed of adjustment parameter (γ_7).

4 Results

4.1 Descriptive analysis

To discern valuable insights about the pattern and variability of the selected variables, a comprehensive overview of key statistics is presented in Table 2 below. The average greenhouse gas emissions of 47.48 with standard deviation of 12.46 signifies substantial emission of greenhouse gases in OPEC member countries with significantly differing level of emission among the member countries. Whereas the average energy consumption is around 73.94, revealing a noticeable difference in the consumption

TABLE 3 Correlation matrix.

Variables	(1)	(2)	(3)	(4)	(5)
(1) GHG	1.000				
(2) FDI	−0.157	1.000			
(3) EC	0.613	−0.254	1.000		
(4) lnGDPG	0.376	−0.100	0.456	1.000	
(5) TRADE	−0.244	0.283	−0.265	0.097	1.000

pattern of the member countries. A standard deviation of 32.89 emphasizes fluctuations and suggests that energy consumption is an important element within the context of our analysis. Average foreign direct investment of 1.67 and a standard deviation of 4.85 reflects a moderate variability in net foreign interest in the member countries. Meanwhile, the average GDP growth of member countries is approximately 8.43, signifying a minor difference in the economic output of member countries. This low mean, along with a moderate standard deviation of 1.28 underscores the similarity in economic activities across the member countries. Finally, the average trade flow of 76.35 with a high variability of 38.96 underscores the huge differences in the quantity of trade flows among member countries and the kind of relationship they have with the rest of the world. These means and variabilities underscore the importance of assessing the link between greenhouse gas emissions, foreign direct investment, energy consumption, trade, and economic boom in the OPEC states.

4.2 Correlation analysis

The outcome of the correlation estimations of the selected variables for the study is shown in Table 3. This analysis seeks to investigate the correlations between these variables and determine the presence of multicollinearity, an issue in regression analysis. The data shows that the explanatory factors tested had weak relationships with one another, with the majority of the correlation coefficients falling below the threshold of 0.8. This finding shows that multicollinearity, a condition in which explanatory variables in a model are highly interrelated, is not a major problem in our investigation, allowing us to proceed with confidence. Furthermore, the data unveiled that the contingent variable, greenhouse gas, has a positive correlation with energy utilization and economic prosperity. This indicates that a rise in energy consumption or economic boom will contribute to an increase in greenhouse gas emissions in OPEC nations. FDI and trade, on the contrary, are negatively connected with greenhouse gas emissions, implying that if FDI or trade flow increases, greenhouse gas emissions would decrease. These connections provide valuable insights into the study's key factors.

4.3 Unit root test

Before we advance with the analysis of the aftermath of FDI, energy consumption and GDP growth on GHG emissions in the OPEC member countries, the static nature and the order of integration of the selected variables is examined first using three difference panel unit root tests. Levin-Lin-Chu, Im-Pesaran-Shin unit roots, and Hadri Langrage Multiplier (LM) unit roots tests to assess stationarity and order of integration. These tests are important prerequisite conditions for using ARDL estimation technique. Levin-Lin-Chu and Im-Pesaran-Shin unit roots tests state the null hypothesis of unit roots or non-stationarity in the panel series and as can be seen from Table 4 below, the *p*-values from these tests for GHG emissions, energy consumption log of GDP growth and trade are all >0.05, hence the null hypothesis of non-stationary is not rejected. While only FDI is stationary at level, the other variables are only stationary after taking the first difference. This implies that GHG, energy consumption, lnGDPG and Trade are all integrating of order one [I(1)] variables whereas FDI is integrating of order zero.

In the case of the Hadri LM unit roots test, the null hypothesis states that the panels are stationary and do not contain unit roots. Here, too, the *p*-values from the test for all the variables except for FDI are <0.05, resulting to the non-acceptance of the null hypothesis that the panel series for greenhouse gas, energy consumption, lnGDPG and Trade are stationary at level.

4.4 Cointegration testing results

Since the estimations of the panel unit root tests show different orders of integration for the selected series, there is therefore, a need to determine the existence of any long run connection among the series. ARDL bound test for cointegration of Pesaran et al. (2001) is the ideal candidate in the study context given that the selected variables are either I(0) or I(1) as indicated in Table 4.

As illustrated in Table 5, the computed F-statistics value of 4.1876 is determined to be greater than the upper bound critical value at 1 percent level of significance. This finding implies the existence of a long run cointegrating connection among the selected series over the study period.

4.5 Panel ARDL estimations

Our choice of panel autoregressive distributed lag (ARDL) methodology is in line with very many studies in the literature (see Sbia et al., 2014; Hanif et al., 2019; Fan and Hao, 2020; Udemba et al., 2020) that use variables with different order of integration. Pesaran et al. (2001) described the technique as robust and versatile with ability to simultaneously estimate both short-run and long-run dynamics even within a small sample framework. The methodology also includes the error correction technique and addresses common regression issue such as endogeneity. This, according to Pesaran et al. (2001) provides comprehensive insights into the dynamic interaction among the variables of interest.

4.5.1 Short – run ARDL estimated results

Table 6 displays the estimations of the short-run ARDL (3,1,1,1) estimations as well as the error correction term coefficients

TABLE 4 Results of panel unit root test.

Test		GHG	FDI	EC	lnGDPG	TRADE
Levin, Lin and Chu t*	Level	5.0233	−4.708***	10.498	1.5305	−0.721
	1st difference	−4.327***	-	−13.49***	−18.247***	−16.361***
Im, Pesran and Shin W-stat	Level	5.0069	−5.259***	8.2309	2.2129	−1.054
	1st difference	−14.79***	-	−12.963***	−17.025***	−16.035***
Hadri LM z-stat	Level	10.568***	3.768	9.238***	8.3673***	−8.98***
Order of Integration		I (1)	I (0)	I (1)	I (1)	I (1)

Number of cross-section id = 12 and Number of periods = 40; *** p < 0.01, ** p < 0.05, * p < 0.1.

TABLE 5 ARDL bounds test for cointegration – ARDL (3, 1, 1, 1) model results.

Estimated values		
Test statistics	Estimated value	K
F - Statistics	4.1876***	(4, 392)
Chi-square	16.751***	
Critical Values of the Bounds Test		
Significance	*Lower Bounds (I0)*	*Upper Bound [I (1)]*
10 percent	1.99	2.94
5 percent	2.27	3.28
1 percent	2.88	3.99

***p < 0.01, ** p < 0.05, * p < 0.1.

TABLE 6 Short – run ARDL equation.

Dependent variable: D (GHG) - ARDL (3, 1, 1, 1)		
Regressor	Coefficient	T-statistics
D (GHG) (−1)	−0.095**	−1.9959
	(0.0476)	
D (GHG) (−2)	−0.0333	−0.4996
	(0.0666)	
D (FDI)	0.0069	0.1661
	(0.0419)	
D (EC)	0.5954	0.7717
	(0.7716)	
D (LnGDPG)	−0.9423	−0.9184
	(1.0261)	
D (TRADE)	0.0169	0.6801
	(0.0249)	
ECT (−1)	−0.0307**	−2.2199
	(0.0152)	

Standard errors reported in parentheses; *** p < 0.01, ** p < 0.05, * p < 0.1.

($ECT_{(-1)}$). The computation of the coefficient error correction term is an important outcome of short-run dynamics since it measures the rate of adjustment. That is how quickly the system returns to equilibrium after being disequilibrated. For the ARDL (3,1,1,1) model, the coefficient of 0.0307 of the error correction term is negative and significant as expected. This suggests that in the current period, around 3 percent of the non-equilibrium from the preceding year's shock have returned to long-term equilibrium.

In the short run, except for immediate past GHG emissions, all the selected variables in the model are statistically insignificant at the conventional 10 percent level of significance. This suggests that lagged differences of FDI, energy consumption, economic prosperity and trade do not affect GHG emissions in the OPEC member states. However, the lagged difference in the previous year's GHG emissions negatively impacted the lagged difference of GHG emissions in current year.

4.5.2 Long – run ARDL estimated results

Table 7 depicts the long-run ARDL (3,1,1,1) coefficient estimates of the influence of FDI, energy consumption and GDP growth on GHG emissions of the OPEC member states. The results revealed that energy consumption and GDP growth increase GHG emissions whereas, trade flow negatively impact GHG emissions in the member states.

The coefficient estimate for energy consumption indicates that a percent increase in energy consumption will results to a 0.11 percent in GHG emissions in the OPEC member states. While the economic growth in the member states contributes to 7.47 per cent to GHG emissions for every 1 percent increase, trade flow tends to reduce GHG emissions in the member states by 0.37 per cent for every 1 percent rise. Though the impact of FDI on GHG emissions in the OPEC member states is negative, it is statistically insignificant.

5 Discussions

The results from the assessment of the impact of FDI, energy consumption, economic growth and trade flow on GHGs emissions in OPEC member states offer important insights into the interaction of the selected variables and their implications for economic and environmental policies. The descriptive statistics show significant variation in GHG emissions and energy consumption between OPEC members. The correlation study reveals positive correlations between GHG emissions, energy consumption, and economic growth, showing that increases in these variables are linked to increased GHG emissions (Kim, 2020). Conversely, FDI and trade flow are negatively connected with GHG emissions, implying that increased FDI and trade may help to

TABLE 7 Long – run ARDL equation.

Dependent variable: D (GHG) - ARDL (3, 1, 1, 1)		
Regressor	Coefficient	T-statistics
FDI	−0.4191	−1.2899
	(0.3249)	
EC	0.1105**	2.5629
	(0.0431)	
LnGDPG	7.467***	6.9292
	(1.0776)	
TRADE	−0.3667***	−3.9397
	(0.0931)	

Standard errors reported in parentheses; ***p < 0.01, ** p < 0.05, * p < 0.1.

reduce emissions. These findings call into question certain long-held assumptions about environmental policy. For example, the positive correlation between economic growth and GHG emissions supports the Environmental Kuznets Curve (EKC) hypothesis, which states that economic development initially degrades the environment but eventually improves it as income levels rise (Wang et al., 2024). However, the negative correlation between FDI, trade, and GHG emissions suggest that globalization and international investment may introduce cleaner technologies along with better production methods, contrary to the notion that economic globalization always worsens environmental issues.

The unit root tests reveal that, while FDI is stationary at level, the other factors (GHG, EC, lnGDPG, and trade) become stable only after accounting for the initial difference. This means that these factors are integrated of order one, apart from FDI, which is integrated of order zero. The cointegration test results demonstrate a long-run equilibrium relationship between the variables, which strengthens the trustworthiness of the ARDL model analysis. The identification of multiple orders of integration among the variables emphasizes the complexities of their interactions. The long-run cointegration of these variables suggests that policies aimed at a particular factor, such as energy consumption, will result in long-term consequences for GHG emissions, economic growth, and trade. This interdependence needs a comprehensive approach to policy creation, with energy, economic, and environmental policies coordinated to accomplish sustainable development goals.

The short-run ARDL results show that only the previous year's GHG emissions have a substantial impact on current GHG emissions whereas the other variables are statistically inconsequential. This shows that GHG emissions have a degree of inertia, with past emissions levels influencing present levels. Energy consumption and economic growth have a positive long-term influence on GHG emissions, whereas trade flows have a negative one. These long-term findings have major policy consequences. The positive association between energy consumption and GHG emissions emphasizes the need for OPEC countries to move to cleaner energy sources in order to reduce environmental damage. Given the significant relationship of economic growth to GHG emissions, economic policy should incorporate environmental considerations to assure long-term growth. The negative effect of trade flow on GHG emissions may indicate that trade policies that promote environmentally friendly procedures and innovations can help mitigate emissions.

6 Conclusion and policy recommendations

6.1 Concluding remarks

In their pursuit of economic development, OPEC countries find themselves at a critical juncture where their development ambitions and environmental commitments collide. This study delves into the interrelationship between FDI, energy consumption, GDP growth, and GHG emissions in OPEC nations, revealing a complex web of factors that require nuanced policy responses. The correlation study reveals positive correlations between GHG emissions, energy consumption, and economic growth, showing that increases in these variables are linked to increased GHG emissions. Conversely, FDI and trade flow are negatively connected with GHG emissions, implying that increased FDI and trade may help to reduce emissions. Energy consumption and economic growth have a positive long-term influence on GHG emissions, whereas trade flows have a negative one. These findings are important and consistent with similar studies done by Pao and Tsai (2011), Leitão (2015), and Osobajo et al. (2020). The positive relationship between energy consumption, GDP growth, and greenhouse gas emissions highlights the urgency of implementing measures that balance economic prosperity and environmental protection. At the same time, the negative correlation with trade flows suggests that strategic trade policies may provide a way to reduce environmental pressures and balance economic development and environmental responsibility.

The positive relationship between GHG emissions, energy consumption, and economic growth found in this study is consistent with previous studies in OPEC and other regions. However, many studies have shown that economic growth due to industrialization and increased energy consumption increases GHG emissions. For example, a study by Chandran and Tang (2013) found a positive correlation between GDP growth and CO_2 emissions in Malaysia, a non-OPEC developing country, showing the relevance of this relationship globally. Similarly, in the context of OPEC, a study by Al-Mulali and Ozturk (2016) found that GDP growth and energy consumption are the main drivers of CO_2 emissions in these countries. Their findings are consistent with our results and confirm the assumption that GHG emissions increase as OPEC countries grow economically and consume more energy.

In the context of OPEC countries, the finding that FDI and trade flows are negatively correlated with GHG emissions can be considered new knowledge, particularly if previous studies predominantly supported the "pollution haven" hypothesis in similar contexts. These insights contribute to understanding how, under certain circumstances, FDI and trade can support environmental sustainability. However, the positive correlation between GHG emissions, energy consumption, and economic growth is consistent with the existing literature, confirming the well-documented relationship that economic activity and energy use contribute to higher emissions. The specific context

of OPEC countries adds value to the generalizability of these results but does not necessarily present a groundbreaking deviation from existing knowledge. Our findings are important for informing OPEC countries' policies and suggest that strategies to attract FDI and improve trade can be environmentally beneficial when combined with technology transfer and strong environmental laws. These insights are particularly relevant in OPEC countries that face the dual challenge of economic growth and environmental sustainability.

6.2 Policy recommendation

Several policy implications can be drawn from the results and discussions presented.

Given the positive relationship between energy consumption and GHG emissions, policies aimed at promoting energy efficiency in OPEC member countries can be demonstrated. This includes projects such as setting energy efficiency standards, promoting energy efficiency technologies, and implementing energy saving practices in businesses and households. OPEC countries can reduce GHG emissions by focusing on reducing energy consumption without compromising economic activity. Improving energy efficiency in various sectors not only reduces emissions, but also leads to cost savings and improved energy security. However, given the positive relationship between economic growth (as measured by GDP growth) and GHG emissions, policies must balance economic development with environmental sustainability. This can include measures to decouple economic growth from emissions growth, such as investing in clean technologies, promoting circular economy practices, and adopting consumption and production models.

By promoting innovation and incorporating sustainable practices into economic planning, OPEC countries can pursue growth opportunities that reduce environmental impacts and ensure economic sustainability. Despite the statistically insignificant impact of FDI on GHG emissions, policies can still encourage environmentally sustainable FDI. This may include providing incentives for green investments, encouraging green technologies, and including environmental criteria in the investment selection process to ensure that FDI contributes to reducing emissions and protecting the environment. Encouraging FDI linked to environmental goals will help OPEC countries not only promote economic growth but also attract investments that support their commitments to reduce GHG emissions and improve more than just the environment. Also, given the negative correlation between trade flows and GHG emissions, policies can focus on promoting climate-friendly trade. This may include supporting trade agreements that include environmental measures, promoting the adoption of clean technologies in international trade, and facilitating the exchange of best practices in environmental management between and among trading partners. By incorporating environmental considerations into their trade policies, OPEC countries can use their trade relationships to promote sustainable production and reduce the total carbon emissions of traded goods and services.

Based on findings of a positive relationship between energy consumption and GHG emissions, policies can target investments in renewable energy sources and clean technologies. This includes providing incentives for solar, wind, hydro and other renewable energy sources to reduce dependence on fossil fuels and reduce GHG emissions. Thus, accelerating the transition to renewable energy will not only help mitigate emissions, but also strengthen energy security and create new economic opportunities in emerging green sectors. These detailed policy implications derive directly from the results and discussions presented, focusing on addressing the relationships between key variables such as energy consumption, economic growth, FDI, trade flows and GHG emissions in the context of OPEC member states. These recommendations aim to align policies with the unique economic and environmental dynamics of OPEC countries to support sustainable development and help these countries balance their economic ambitions with their environmental responsibility.

6.3 Suggestions for further studies

To improve our understanding of these relationships and fill potential gaps in the existing literature, future research efforts may explore the following avenues:

1. Conduct more detailed temporal analyses to capture changes over specific time periods and gain a more nuanced picture of how the connection between FDI, energy consumption, GDP growth, and greenhouse gas emissions change over time. This may include examining short-term fluctuations and identifying critical periods of impact.
2. Oversee individual country-specific studies within the OPEC framework to take into account heterogeneity among member countries. Different OPEC countries may have different patterns and drivers of energy use, economic growth, and environmental impacts.
3. Conduct sector analysis to uncover how different industries in OPEC member countries contribute to greenhouse gas emissions. This could provide targeted insights for policy development and sector-specific interventions to improve environmental sustainability.
4. Evaluate the effectiveness of specific policy interventions to reduce greenhouse gas emissions in OPEC countries. This could include assessing the influence of renewable energy incentives, energy efficiency measures, and green investment policies on the observed relationships.
5. Employ dynamic modeling techniques to capture the evolving nature of the association between FDI, energy consumption, GDP growth, and greenhouse gas emissions. This could involve incorporating lagged effects, feedback loops, and non-linear dynamics to better represent the complexities of the system.
6. Complement quantitative analysis with qualitative research, including interviews with policymakers, industry leaders, and environmental experts. Qualitative insights allow a deeper perception of the contextual elements that determine policy decisions and industry practices.

7. Investigate the influence of global climate policies and agreements on the observed relationships. Assess how international efforts to reduce greenhouse gas emissions impact the decision-making processes of OPEC member countries.

By moving into these research suggestions, the complex relationships between economic development, energy use, and environmental sustainability in OPEC countries will better be understood. These insights are important for policymakers, environmentalists, and industry stakeholders to develop effective strategies to achieve a harmonious balance between economic prosperity and environmental protection.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: https://databank.worldbank.org/source/world-development-indicators.

Author contributions

AG: Conceptualization, Data curation, Funding acquisition, Investigation, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. LJ: Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. MJ: Funding acquisition, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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