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The impact of renewable energy on CO₂ emissions in Middle Eastern and BRICS economies

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Environmental pollution, exacerbated by rising CO₂ emissions and deteriorating air quality, presents significant challenges to sustainable development worldwide. This study investigates the factors influencing environmental pollution in Middle Eastern and BRICS countries from 1995 to 2020, employing various econometric methods, including CIPS and CADF unit root tests, the Westerlund panel cointegration test, and the Pairwise Dumitrescu–Hurlin panel causality test, along with robustness checks via DOLS. The results for BRICS nations indicate a unidirectional causality from renewable energy consumption to CO₂ emissions, suggesting that increased renewable energy usage effectively lowers emissions, although CO₂ emissions significantly affect energy consumption without reciprocal influence. In contrast, Middle Eastern countries reveal a bidirectional causality between renewable energy and CO₂ emissions, indicating that increases in renewable energy not only mitigate emissions but also respond to emission level changes. Notably, energy consumption neither significantly influences CO₂ emissions nor is affected by them in this region. In both regions, trade openness influences CO₂ emissions unidirectionally, while FDI shows no significant predictive power for emissions levels. The DOLS results demonstrate that a unit increase in renewable energy reduces CO₂ emissions by 0.22% in the Middle East and by 0.66% in BRICS countries, emphasizing the effectiveness of renewable energy investments in mitigating climate change. These findings underline the importance of developing policies that promote renewable energy while carefully examining the impacts of FDI and trade on emissions.

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Introduction

The global energy landscape is undergoing significant change due to increasing concerns about carbon dioxide (CO₂) emissions, climate change, fossil fuel depletion, and the need for sustainable development. Renewable energy sources present a viable alternative to fossil fuels, with the potential to reduce greenhouse gas emissions and mitigate environmental pollution. This shift is further driven by international agreements such as the 2015 Paris Agreement, which aims to limit global warming to well below two degrees Celsius, ideally capping it at 1.5 degrees Celsius (Robiou du Pont and Meinshausen 2018; Schlessner et al. 2022). To meet these targets, rapid reductions in fossil fuel consumption and a transition to low-carbon energy are essential, making technological innovations and adoption of renewable energy crucial.

CO₂ emissions are a major contributor to environmental pollution, significantly affecting air quality and global warming (Hadipoor et al. 2021; Nunes 2023). Although CO₂ is naturally occurring and plays a role in the greenhouse effect, excessive concentrations lead to detrimental ecological consequences. Therefore, reducing CO₂ emissions is imperative for mitigating climate change and minimizing its adverse effects (Addis and Cheng, 2023; Cheng et al., 2023). Strategies such as enhancing energy efficiency and transitioning to sources of renewable energy are vital in curbing CO₂ emissions and combating environmental pollution.

This study focuses on the factors influencing environmental pollution in two critical groups: Middle Eastern countries, namely, Yemen, the United Arab Emirates (UAE), Syria, Saudi Arabia, Qatar, Oman, Lebanon, Kuwait, Jordan, Israel, Iraq, and Bahrain; and BRICS nations, namely, Brazil, Russia, India, China, and South Africa. To the best of our knowledge, this is the first attempt to analyze and compare environmental pollution between the Middle Eastern and BRICS regions. Analyzing these regions is essential because of their substantial impact on global environmental trends and their role as key players in energy consumption and production. The Middle East is characterized by its vast oil reserves and energy-intensive economies, leading to significant greenhouse gas emissions and air quality deterioration (Kouyakhi 2022; Tazikeh et al. 2025). BRICS nations, on the other hand, present a complex landscape of rapid industrialization and urbanization, contributing to considerable environmental pollution (Addis and Cheng, 2023). Both the Middle East and BRICS nations are pivotal in the global economy, influencing energy markets and environmental sustainability efforts. Their strategic importance is underscored by their roles in international trade and investment flows, which can either mitigate or exacerbate environmental challenges. As such, a comparative analysis of these regions offers critical insights into the complex nature of environmental pollution and the diverse strategies needed to address it effectively on a global scale. Understanding the interplay of economic, environmental, and political factors in these regions can inform policymakers and stakeholders, as they face the urgent challenges of climate change and sustainable development (Addis and Cheng, 2023; Cheng et al., 2023; Mahmood et al. 2023).

This comparison is important because both groups, despite being comprised of emerging economies, have distinct energy profiles and consumption patterns. Middle Eastern countries primarily rely on fossil fuels (Kouyakhi 2022; Tazikeh et al. 2025), while BRICS nations utilize a more varied mix, including renewable energies (Asif et al. 2024). The BRICS countries hold a significant position in the global energy landscape (Khan et al. 2024; Meng et al. 2025; Naz et al. 2024). Their differing stages of economic development also influence energy policies, impacting renewable energy adoption and CO₂ emissions trajectories. Additionally, the role of the Middle Eastern countries in global energy markets and the rapid growth of BRICS economies

highlight the significance of understanding regional dynamics in energy transition and climate change (Naz et al. 2024; Tazikeh et al. 2025). Insights gained from this comparison can inform tailored policy strategies that address the unique challenges and opportunities within each region.

The environmental pollution in BRICS and Middle Eastern countries is driven by complex factors, including economic growth, energy consumption, industrial activities, FDI inflows, and trade openness (Addis and Cheng, 2023; Cheng et al., 2023; Alam et al. 2024; Mahmood et al. 2023). While economic growth can enhance resources for environmental protection, it may also lead to greater pollution without strong regulations (Liu et al. 2023; Osuntuyi and Lean 2022; You et al. 2025). Regions that attract FDI for sustainable projects often experience a decrease in pollution, whereas those focused on resource extraction face environmental challenges (Hunjra et al. 2024). Trade openness can either improve environmental outcomes through cleaner technology imports or worsen pollution due to lax regulations (Barkat et al. 2024; Le et al. 2016). Another critical factor is fossil fuel consumption, which is correlated with increased pollution, while transitioning to sources of renewable energy can significantly enhance environmental health (Nkalu 2023; Wang et al. 2023). Countries prioritizing renewable energy tend to have lower pollution levels, although adoption varies on the basis of resources, public awareness, policies, technology, and geopolitical conditions (Karlilar Pata and Balcilar 2024).

BRICS nations have made significant advancements in the production of renewable energy, with China emerging as the largest investor in solar and wind power infrastructure worldwide (Chen and Xu 2022; Gielen et al. 2019). India has also expanded its solar capabilities (Kumar and Majid 2020; Lu et al. 2020), whereas Brazil has become a major player in biofuel production, leveraging sugarcane resources (Vega et al. 2024). In contrast, Middle Eastern countries continue to emphasize oil and gas, with energy strategies heavily reliant on fossil fuels (Hassan et al. 2023; Alnour and Kocak 2025). Despite initial efforts in renewable solutions, such as solar programs in the UAE and Saudi Arabia's Vision 2030 plan, these transitions lag behind those of BRICS nations (Islam and Ali 2024). This disparity highlights differing regional energy priorities and the need for a more integrated approach to sustainable development. Technological advancements and robust research and development (R&D) efforts in both BRICS and Middle Eastern nations have improved renewable energy efficiency (Addis and Cheng, 2023; Cheng et al., 2023; Hassan et al. 2023; Xu and Hussain 2023). China and India, driven by ambitious government policies, are now global leaders in solar energy (Wang et al. 2023; Wu and Wan 2024), whereas Middle Eastern countries such as the UAE and Saudi Arabia are investing in large-scale renewable projects, such as the UAE's Mohamed bin Rashid Al-Maktoum Solar Park and Saudi's NEOM megacity project initiative (Koch 2023; Yusuf and Abdulmohsen 2023). Together, these developments position both BRICS countries and Middle Eastern countries as crucial players in the global energy transition, addressing their socioeconomic and environmental challenges.

Despite these technological advancements, environmental pollution, driven by industrialization, high energy consumption, population growth, and rapid urbanization, remains a significant challenge for both BRICS nations and Middle Eastern nations (Afifa et al. 2024; Briggs 2003). In BRICS countries, significant increases in pollution have been noted in urban and industrial centers due to economic growth (Addis and Cheng, 2023; Cheng et al., 2023). In recognition of these issues, BRICS nations are implementing policies aimed at reducing emissions, improving resource management, and attracting foreign investment in cleaner technologies, particularly within renewable energy sectors

(Alam et al. 2024; Wang et al. 2023). Similarly, Middle Eastern countries, addressing pollution from fossil fuel reliance and urban expansion, are enacting stringent regulations and ambitious emission reduction targets (Al-mulali 2011; Ben Cheikh and Ben Zaied, 2021; Mahmood et al. 2023). Programs such as Qatar's National Vision 2030 and the UAE's Green Economy Strategy showcase their commitment to sustainability and economic diversification (Cochrane and Al-Hababi 2023; Koch 2023). These efforts in both regions reflect a growing understanding that long-term economic growth must align with environmental sustainability while addressing socio-economic challenges.

This study aims to enhance existing knowledge in several key areas. To the best of our knowledge, this represents the initial effort to examine and compare environmental pollution between the Middle Eastern and BRICS regions. *First*, by comparing two distinct groups of countries, fossil fuel-dependent Middle Eastern nations (Alnour and Kocak 2025; Hassan et al. 2023) and the diverse economies of BRICS countries (Addis and Cheng, 2023; Cheng et al., 2023), this study reveals valuable best practices for achieving sustainable development goals while addressing challenges such as environmental pollution. By examining these regions together, we provide a comparative analysis that highlights distinct economic and environmental contexts, which is underexplored in current research. This comparative approach adds depth to our understanding of how diverse economic contexts shape the relationships between renewable energy and CO₂ emissions. *Second*, it offers a thorough examination of the causal and long-term relationships among renewable energy, FDI inflows, energy consumption, trade openness, CO₂ emissions, and economic growth within both regions. *Third*, by utilizing an array of econometric techniques, including CIPS and CADF unit root tests, Westerlund panel cointegration tests, and the Pairwise Dumitrescu–Hurlin causality test, this study ensures rigorous statistical validation of findings. The incorporation of DOLS as a robustness check strengthens the analysis, establishing a reliable framework for interpreting the causative relationships involved and ensuring the derived relationships are statistically sound and resilient to potential pitfalls in data analysis. *Finally*, the findings will aid policymakers in understanding the opportunities and challenges presented by renewable energy adoption, facilitating the identification of optimal strategies and policy recommendations for promoting renewable resources, minimizing environmental impacts, and achieving sustainable economic growth.

This study is unique due to its thorough examination of the relationship between renewable energy consumption and CO₂ emissions across two distinct regions. By comparing the BRICS nations with the Middle Eastern countries, we establish a comparative framework that paves the way for future investigations into how other regions might also display distinctive interactions within energy and environmental contexts. Furthermore, our robust econometric methodology sets this study apart from previous research, which frequently employs more simplistic models, thereby increasing the validity and breadth of our results.

Literature review

Environmental pollution is a complex issue influenced by industrial operations, agricultural practices, transportation, urbanization, and other human activities (Zeng et al., 2025; Beyene 2022; Duan 2025; Thu et al. 2022). Industrial processes release harmful pollutants into the air and water (Gomes da Silva and Gouveia 2020), whereas agricultural practices that use pesticides and fertilizers contribute to soil degradation and water contamination (Zeng et al. 2025; Baweja et al. 2020). Additionally, transport systems reliant on fossil fuels emit substantial amounts of CO₂, exacerbating the global climate crisis (Li et al., 2024).

Clearly, as economies grow, industrial and urban expansion can result in increased environmental pollution in the absence of sustainable strategies.

Environmental pollution is a pressing concern, especially in rapidly developing regions such as the Middle East and BRICS countries. Both regions are characterized by unique economic structures, abundant natural resources, and significant challenges in reconciling economic advancement with environmental protection. While BRICS nations face intensified industrialization and urbanization, leading to increased air and water pollution, deforestation, and biodiversity loss (Chen et al. 2025; Udeagha and Ngepah 2023), Middle Eastern countries are navigating the complexities of transitioning their oil-dependent economies toward diversification and reduced reliance on fossil fuel (Al-mulali 2011; Mahmood et al. 2023). This transition is pivotal for achieving enduring sustainability and economic resilience amidst fluctuating oil prices and a global shift to renewable energy. Furthermore, many Middle Eastern nations are vulnerable to climate change effects, including water scarcity and extreme heat, which threaten economic stability and social coherence (Alnour and Kocak 2025; Hassan et al. 2023; Yongsheng and Yingquan 2025).

This literature review synthesizes existing research on the factors driving environmental pollution in the Middle East and BRICS regions. Key variables such as economic growth, renewable energy, trade openness, energy consumption, and FDI inflows significantly influence environmental pollution, growth strategies, and sustainability initiatives (Addis and Cheng, 2023; Cheng et al., 2023; Hoa et al. 2024). Rapid economic growth alongside increased fossil fuel consumption and industrialization serves as a primary driver of pollution in both regions. Studies by Wang et al. (2023) and Wu and Wan (2024) indicate that economic development, particularly in countries such as China and India, is correlated with increased emissions. A similar trend is evident in the Middle East, where industrial activities in oil-dependent economies exacerbate air and water pollution (Al-mulali 2011; Osipov et al. 2022; Xu and Hussain 2023). The nexus between pollution and energy consumption highlights the pressing need for a transition to sources of renewable energy. Scholars note that while both regions are gradually adopting renewable energy and regulatory frameworks that promote sustainability, progress varies significantly (Alam et al. 2024; Hassan et al. 2023).

Opoku et al. (2022) investigated the nexus between environmental pollution and inward FDI, analyzing longitudinal data across a cohort of 103 developing economies spanning between 1970 and 2019. Their findings indicate that pollution adversely affects FDI inflows, particularly in Middle Eastern and BRICS nations. Similarly, via a panel threshold model, Wang and Wang (2021) examine the impact of trade openness on carbon intensity across 104 countries from 2000–2014. They conclude that trade openness effectively diminishes carbon intensity in lower-middle-income and high-income countries, unlike in the upper-middle-income group. Other scholars, on the other hand, argue that FDI and trade openness may correlate negatively with environmental pollution by facilitating the introduction of cleaner technologies, which enhance overall environmental performance (Padhan and Bhat 2024; Wang et al. 2024). Additionally, some research has focused on how income inequality and political instability shape public awareness and environmental policies in these regions (Ben Cheikh and Ben Zaied 2021; Sofuoğlu and Ay 2020; Zhao et al. 2021).

The theories and models that explain pollution trends in the Middle East and BRICS nations underscore the intricate relationship between economic growth and environmental degradation, revealing distinct characteristics within each region. In the Middle East, traffic-related air pollution (TRAP) plays a crucial role in deteriorating urban air quality. Research shows that TRAP

contributes to more than 50% of particulate matter (PM) levels in cities (Nasser et al. 2015). This issue is compounded by rapid urbanization and an increase in vehicle emissions, driven by population growth and economic development over the past few decades (Isaifan 2023). In contrast, the pollution profiles of BRICS countries reflect their diverse economic foundations and varying stages of industrial development (Apergis et al. 2023; Nawsherwan et al. 2024). The “pollution haven” hypothesis posits that FDI in these nations may increase carbon emissions, largely due to weaker environmental regulations (Demena and Afesorgbor 2020). However, some research suggests that such investments can also foster improved environmental management practices (Apergis et al. 2023; Liu 2022).

While both regions face significant challenges, such as elevated levels of particulate matter and the associated health risks of air pollution, their responses tend to differ markedly. Some BRICS nations are successfully implementing effective environmental policies, whereas others continue to battle high emissions linked to industrial growth (Elalouf 2023). For example, China’s rapid industrialization has not only led to substantial air quality challenges but also spurred significant investments in renewable energy and pollution control technologies (Tian et al. 2020). In the Middle East, on the other hand, pollution is significantly influenced by local factors, including arid climatic conditions and geopolitical complexities that hinder effective environmental governance (Isaifan 2023). Although both the Middle East and BRICS countries generally face formidable pollution issues, the root causes and responses differ significantly. A deeper understanding of these dynamics is essential for formulating targeted policies that effectively address the unique environmental challenges faced by each region. In order to provide a comprehensive overview of the existing research on environmental influences, Table 1 summarizes the key findings and methodologies from relevant literature.

While the Middle East and BRICS nations face distinct challenges and opportunities regarding environmental pollution, a comparative study is essential for understanding the unique dynamics influencing their environmental policies and outcomes. The geopolitical and economic contexts of these regions may reveal contrasting patterns in economic growth, resource availability, and environmental crises. This study aims not only to analyze the factors influencing CO₂ emissions but also to conduct a comprehensive empirical investigation into the interrelationships among renewable energy, energy consumption, inward FDI, trade openness, economic growth, and CO₂ emissions in these two regions. This analysis highlights varying commitments to sustainable practices and identifies innovative strategies for effectively reducing pollution and improving resource efficiency.

Methodology

The shift towards renewable energy sources is increasingly acknowledged as a vital approach for reducing CO₂ emissions. A growing body of scholarly research has aimed to explore and quantify this relationship (Addis and Cheng, 2023; Mirziyoyeva and Salahodjaev 2023; Sharif et al. 2024; Thi et al. 2023; Zakarya et al. 2015). The theoretical foundations supporting this role are diverse, encompassing technological, economic, and policy-oriented dimensions (Budzianowski 2012; Maamoun et al. 2020; Yang et al. 2022).

Renewable energy’s effectiveness in curbing CO₂ emissions primarily lies in its capacity to replace energy derived from fossil fuels (Ilbahar et al. 2022; Saidi and Omri 2020). The combustion of fossil fuels such as coal, oil, and natural gas results in the release of significant quantities of CO₂, which contributes to escalating greenhouse gas levels in the atmosphere (Ilbahar et al.

2022; Suman 2021). In contrast, renewable energy technologies leverage naturally replenished resources, enabling energy production with negligible direct CO₂ emissions (Ilbahar et al. 2022; Lu et al. 2025; Saidi and Omri 2020).

Moreover, empirical research conducted across various countries and regions provides robust evidence supporting the theoretical premise that renewable energy can effectively reduce CO₂ emissions (Addis and Cheng, 2023; Budzianowski 2012; Saidi and Omri 2020; Suman 2021; Yang et al. 2022; Zakarya et al. 2015). This study focuses on the theoretical and empirical foundations regarding the role of renewable energy in reducing CO₂ emissions in the context of the Middle East and BRICS countries.

Data source. The study employed panel data spanning from 1995 to 2020, encompassing 12 Middle East and BRICS countries, to examine the influencing factors of environmental pollution by using CO₂ emissions as an indicator. The choice of variables and data was guided by sustainable development indicators and economic theories, all aimed at improving economic development, energy efficiency, and environmental quality.

The selected timeframe and data were based on what was available, with a focus on examining the causal relationships between CO₂ emissions and renewable energy as well as other econometric factors over a substantial period. Furthermore, the chosen variables were aligned with economic theories and sustainable development indicators, ensuring a comprehensive evaluation of economic progress and environmental quality (Ali et al. 2022; Dong et al. 2019, 2020; Kahia et al. 2019). The data incorporated in this study were derived from reliable sources, including the WDI (World Development Indicators) and Our World in Data. Table 2 lists the sources of data for the variables included in this study.

In this study, CO₂ emissions are identified as the dependent variable because they are influenced by various factors, including energy consumption, economic growth, renewable energy, trade openness, and FDI inflows. Furthermore, CO₂ emissions have a significant effect on environmental health, ecosystems, and overall welfare (Hadipoor et al. 2021; Nunes 2023).

Figure 1 shows a comprehensive description of a conceptual framework diagram that outlines the relationships among the key variables, followed by explanations of the effects.

The conceptual framework connecting RE, EC, FDI, TO, and CO₂ emissions reflects intricate interdependencies (Addis and Cheng, 2023; Xuan 2025). Renewable energy usage positively influences energy consumption by reducing reliance on fossil fuels while simultaneously decreasing CO₂ emissions, as renewables generate minimal emissions (Iqbal et al. 2023). Increased energy consumption typically drives higher CO₂ emissions, particularly from fossil fuel sources, and may impede further renewable energy adoption if prioritized over cleaner alternatives (Addis and Cheng, 2023; Alharthi et al. 2021). FDI often correlates positively with trade openness, facilitating the exchange of goods and technologies that can enhance energy consumption patterns (Menyari 2024; Xuan 2025). While FDI can bolster renewable energy infrastructure, it may also divert attention towards fossil fuel projects based on investor interests (Balli et al. 2023; Mahmood et al. 2023). Trade openness can heighten energy consumption through increased import and export of energy resources, potentially leading to greater emissions but also fostering cleaner technologies (Khan et al. 2025). Generally, the interactions among these variables underscore the need for coherent policies that balance economic growth, foreign investment, and environmental sustainability.

To achieve the study’s objectives and analyze the causal nexus between the variables in the study across Middle Eastern and BRICS nations, panel data analysis will be employed. This will

Table 1 Summary of literature on environmental influences.

Author(s)	Countries/regions	Methods	Analyzed variables	Results
Dissanayake et al. (2023)	152 countries (1990–2019)	Granger causality	Renewable energy, nonrenewable energy, CO ₂ emissions, GDP	Causality between GDP and CO ₂ emissions is unidirectional.
Udeagha and Muchapondwa (2023)	BRICS (1960–2020)	EKC hypothesis	CO ₂ emissions, GDP, GINOV (green innovation), CRI (composite risk index), RERD (renewable energy research and development), EPS (environmental policy stringency)	EPS, GINOV, and RERD play a role in a sustained reduction of CO ₂ emissions over time. Conversely, CRI and GDP exacerbate CO ₂ emissions.
Chen et al. (2020)	103 countries (1995–2015)	Threshold model	Renewable energy, CO ₂ emissions, Energy efficiency, GDP growth	Renewable energy significantly boosts economic growth in developing (non-OECD) nations and contributes positively in OECD countries, while showing no significant influence on economic progress in developed countries.
Thi et al. (2023)	53 countries (1990–2019)	FMOLS, DOLS, GMM estimator	Renewable energy, trade openness, population, tourism, FDI, GDP, innovation, CO ₂ emissions	Trade openness, renewable energy, and innovation lower CO ₂ emissions, while tourism exacerbates environmental degradation.
Yilanci et al. (2020)	BRICS (1982–2014)	Bootstrap ARDL	FDI, Energy consumption, CO ₂ emissions	FDI has mixed effects, while energy consumption has a palliative effect.
Wang and Zhang (2021)	182 countries (1990–2015)	Econometric model	Trade openness, CO ₂ emissions, GDP, population, renewable energy	Trade openness reduces CO ₂ emissions in upper-middle-income and high-income economic countries, with no significant influence on lower-middle-income nations; however, in low-income countries, it increase carbon emissions. It has a positive decoupling impact on economic growth in wealthier nations but a negative impact on poorer countries.
Wang et al. (2023)	67 countries (1990–2019)	Panel data approach	FDI, CO ₂ emissions, GDP per capita, trade openness, population, industrial structure	An inverted U-shaped EKC is observed in 67 sampled nations. The impact of FDI on CO ₂ emissions fluctuates based on income levels, transitioning from advantageous to detrimental as income increases.
Wang et al. (2024)	114 countries (2002–2015)	Production function, extended IPAT theory	FDI, trade openness, human capital, energy consumption, GDP, CO ₂ emissions	FDI can stimulate economic growth while also contributing to higher CO ₂ emissions. On the other hand, greater openness to trade tends to boost economic growth without significantly increasing CO ₂ emissions.
Mirziyoyeva and Salahodjaev (2023)	50 countries (2000–2019)	GMM estimator	Renewable energy, tourism, GDP per capita, population, CO ₂ emissions	Renewable energy sources help lower CO ₂ emissions. Additionally, the relationship between GDP per capita and CO ₂ emissions is represented by an inverted U-shape.
Azam and Haseeb (2021)	BRICS (1990–2018)	FMOLS, DOLS, CS-ARDL	Renewable energy, nonrenewable energy, FDI inflows, GDP, trade, and tourism	Both types of energy utilization (i.e., renewable and nonrenewable) are positively contribute to FDI inflows.
Alam et al. (2024)	14 MENA countries (1990–2011)	GMM estimator	Energy consumption, CO ₂ , GDP per capita, population, financial development, urbanization, energy consumption, trade openness	There exists uni-directional causality from energy consumption to CO ₂ emissions, and bi-directional causal relationship between economic growth and pollutant emissions
Asif et al. (2024)	BRICS countries (2004–2023)	Fixed-effect model	Renewable energy consumption, technology innovation, economic growth, financial development, trade openness, CO ₂	Renewable development positively impact environmental sustainability; however, economic growth negatively affects it.
Tukhtamurodov et al. (2024)	MINA and BRICS countries (2000–2018)	ARDL, PMG	CO ₂ , renewable energy, FDI, trade openness, trade, GDP, and energy consumption	FDI has positive impact on CO ₂ emissions, whilst renewable energy has detrimental effect.
Yang et al. (2024)	BRICS (1990–2018)	MMQR	Load capacity factor, energy production, CO ₂ emissions	Identified key determinants affecting the load capacity factor in BRICS countries.
Magazzino and Mele (2025)	Russia (1970–2017)	Machine Learning Algorithm	CO ₂ emissions, energy use, economic growth	Economic growth leads to an increase in energy consumption and carbon dioxide emissions.
Magazzino et al. (2021)	Brazil (1990–2018)	Machine Learning Experiment	Renewable energy, economic growth, impacts of COVID-19	Found a significant relationship between renewable energy consumption and economic growth during the COVID-19 pandemic.

Table 2 Variables and data sources.

Variables	Symbols	Units	Source
CO ₂ emissions	CO ₂	Metric tons per capita	WDI (2023)
Renewable energy	RE	Percent of total final energy consumption	WDI (2023)
Foreign direct investment	FDI	Net inflows (% of GDP)	WDI (2023)
GDP per capita	GDP per capita	Current US\$	WDI (2023)
Energy consumption	EC	Kg of oil equivalent per capita	Our World in Data (2023)
Trade openness	TO	Trade (% of GDP)	Our World in Data (2023)

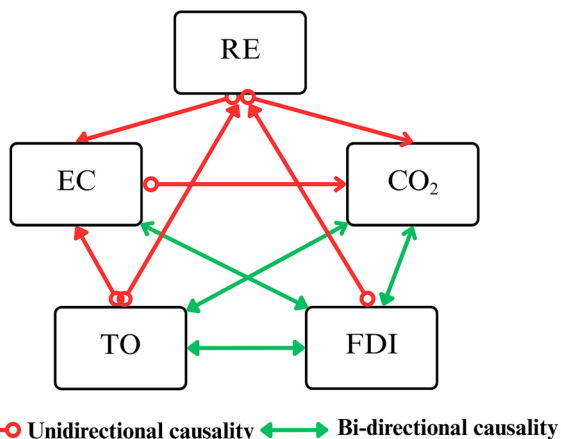


Fig. 1 Conceptual framework diagram that outlines the relationships among the key variables. This figure presents a conceptual framework that visually represents the relationships among the key variables in our study: Renewable Energy (RE), Energy Consumption (EC), Foreign Direct Investment (FDI), Trade Openness (TO), and CO₂ Emissions. The red arrows indicate a directional causality, pointing to a one-way influence from one variable to another, while the green arrows represent bidirectional causality, suggesting that the relationships are reciprocal.

leverage established econometric techniques such as the Pairwise Dumitrescu–Hurlin panel causality test to examine relationships between economic indicators, the CIPS (Cross-sectionally Augmented Im-Pesaran-Shin) and CADF (Cross-sectionally Augmented Dickey–Fuller) unit root tests, an advanced panel unit root tests, developed to tackle the challenge of cross-sectional dependence (CD) within panel datasets (Pesaran 2007), the Westerlund (2007) panel cointegration test is an advanced test that specifically addresses CD and assesses the existence of a long-term equilibrium relationship among nonstationary variables, thus making it appropriate for heterogeneous panel studies, and the Dynamic Ordinary Least Squares (DOLS) estimator is to assess the robustness of the models and address the problems of serial correlations and endogeneity. Figure 2 illustrates the methodological framework employed in this study, outlining the key components and processes involved in our research approach in a diagrammatic manner.

Econometric techniques and model specifications. This study adopted a mixed-methods approach that employs a series of quantitative techniques, including the Pairwise Dumitrescu–Hurlin panel causality test, and various panel econometric techniques, such as the cross-sectional dependence (CD) test, second generation panel unit root test (CIPS and CADF), second generation panel cointegration test (Westerlund panel cointegration), and panel dynamic ordinary least squares (DOLS) method. This comprehensive methodological framework is increasingly recognized in the literature as an effective strategy

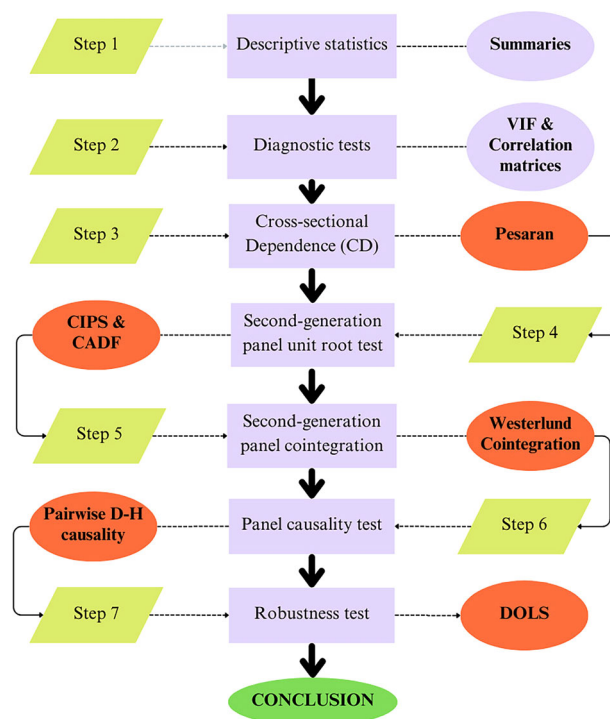


Fig. 2 Methodological framework overview. The methodological framework illustrated in this figure outlines the approach we employed to analyze the impact of renewable energy on CO₂ emissions within Middle Eastern and BRICS economies. It delineates the steps taken throughout the analysis, including the statistical methods and models applied. The flow of arrows indicates the progression of analysis stages, while the orange boxes denote different phases of the methodology. The gray sections highlight types of analysis carried out, and the green area summarizes the study’s conclusions. This framework serves to clarify the comprehensive process followed in this paper.

for addressing complex research questions that span multiple dimensions of data (Al-mulali 2011; Dong et al. 2019, 2020; Jalil and Mahmud 2009; Kahia et al. 2019; Kostakis et al. 2023; Magazzino et al. 2023; Naqvi et al. 2022; Ojekemi et al. 2023; Pesaran 2007; Westerlund 2007; Zakarya et al. 2015).

The CADF test functions as an individual unit root test, evaluating each cross-sectional unit within the panel. It enhances the traditional Augmented Dickey–Fuller (ADF) regression by incorporating cross-sectional averages of the lagged levels and the first differences of the series, thereby addressing common factors that may lead to cross-sectional dependence among the units (Pesaran 2007). The equation for the CADF test applicable to each cross-section i is expressed as:

$$\Delta Y_{it} = \alpha_i + \beta_i Y_{i,t-1} + \chi_i \bar{Y}_{t-1} + \delta_i \Delta \bar{Y}_t + \sum_{j=1}^{p_i} \phi_{ij} \Delta Y_{i,t-j} + \varepsilon_{it} \quad (1)$$

where: ΔY_{it} is the first difference of the variable for unit i at time t ; $Y_{i,t-1}$ is the lagged level of the variable; \bar{Y}_{t-1} and $\Delta \bar{Y}_t$ are the cross-sectional averages of the lagged levels and first differences, respectively, which capture the common factors; α_i represent the intercept for each cross-section; β_i indicate the coefficient of interest; if $\beta_i = 0$, a unit root is present; $\sum_{j=1}^{p_i} \phi_{ij}$; $\Delta Y_{i,t-j}$ are lagged first differences included to ensure the residuals are white noise; and ε_{it} denotes the error term. For each cross-section, a t-statistic for β_i is obtained. The null hypothesis for the CADF test is that a unit root exists for the individual series ($H_0: \beta_i = 0$)

In contrast, the CIPS test is a unit root test conducted across the entire panel, aggregating the individual CADF statistics. It is derived by calculating the simple average of the CADF t-statistics for all cross-sectional units (Pesaran 2007). This study employed the CIPS test statistic, which is determined as follows:

$$CIPS = \frac{1}{N} \sum_{i=1}^N t_{CADF,i} \tag{2}$$

Where: $t_{CADF,i}$ is the CADF t-statistic for the i th cross-section, and N is the number of cross-sections.

Additionally, this study employed the Westerlund (2007) panel cointegration test, a second-generation test, that consists of four statistics. These statistics are based on the error-correction model and test the null hypothesis of no cointegration. The general form of the error-correction model for the Westerlund test is:

$$\Delta Y_{it} = \alpha_{1i} + \alpha_{2it} + \beta_i(Y_{i,t-1} - \chi_i X_{i,t-1}) + \sum_{j=1}^{p_i} \lambda_{ij} \Delta Y_{i,t-j} + \sum_{j=0}^{p_i} \psi_{ij} \Delta X_{i,t-j} + \varepsilon_{it} \tag{3}$$

Where: ΔY_{it} and ΔX_{it} are the first differences of the dependent and independent variables, respectively; α_i is the error-correction parameter, which measures the speed of adjustment to the long-run equilibrium. If $\alpha_i = 0$, there is no cointegration. $Y_{i,t-1} - \chi_i X_{i,t-1}$ represents the error-correction term (ECT), which captures the deviation from the long-run equilibrium.

This study also employed a statistical hypothesis test named the Pairwise Dumitrescu–Hurlin (D-H) panel causality test, developed by Dumitrescu and Hurlin (2012), to determine whether one variable Granger-causes another in a panel data context, where data is collected from several cross-sections over time. The general form of the D-H panel causality test equation for a specific pair of variables, say Y and X , for each individual i in the panel is:

$$\ln Y_{i,t} = \alpha_i + \sum_{k=1}^p \beta_{1i,k} \ln Y_{i,t-k} + \sum_{k=1}^p \beta_{2i,k} \ln X_{i,t-k} + \varepsilon_{i,t} \tag{4}$$

$$\ln X_{i,t} = \alpha_i + \sum_{k=1}^p \beta_{1i,k} \ln X_{i,t-k} + \sum_{k=1}^p \beta_{2i,k} \ln Y_{i,t-k} + \varepsilon_{i,t} \tag{5}$$

In this context, Y_t signifies the variable that is being predicted (dependent), whereas X_t indicates the predictor variable (independent); p represents the count of previous time periods (optimal lag length); t indicates time; α_1 and α_2 are constant terms; β_1 , β_2 , γ_1 , and γ_2 are coefficients for lagged terms; the \ln indexed natural logarithm; and ε_t is the error term considered in the model.

As noted by researchers, Eqs. (4) and (5) are founded on the concept that if variable Y Granger-causes variable X , and vice versa, then past values of Y should provide insights that assist in forecasting X (Dumitrescu and Hurlin 2012). This principle underlies a well-established method frequently employed in econometrics to investigate the connections between economic indicators (Dumitrescu and Hurlin 2012; Shojaie and Fox 2022).

To examine the Granger causality of predictor variables, such as RE (renewable energy), EC (energy consumption), FDI (FDI

inflows), and TO (trade openness), on environmental pollution (CO₂ emissions), this study utilizes the panel Granger causality test (Pairwise Dumitrescu–Hurlin) with a lag length of 1. This approach focuses on the influence of the preceding period’s values of these independent variables. Consequently, the study formulates the following equation that represents the causal relationships between the independent variables and CO₂ emissions:

$$\ln CO_{2i,t} = \alpha_i + \sum_{k=1}^p \beta_{i,k} \ln CO_{2i,t-k} + \sum_{k=1}^p \chi_{i,k} \ln RE_{i,t-k} + \sum_{k=1}^p \delta_{i,k} \ln EC_{i,t-k} + \sum_{k=1}^p \phi_{i,k} \ln FDI_{i,t-k} + \sum_{k=1}^p \varphi_{i,k} \ln TO_{i,t-k} + \varepsilon_{i,t} \tag{6}$$

Where α : constant term; Δ : first difference; β , χ , δ , ϕ , and φ : are the coefficients for the lagged dependent and independent variables for each cross-section; p : optimal lag length set at 1; i : index countries; and ε : serially uncorrelated error term. To eliminate the potential existence of heteroscedasticity and data volatility, this study employed the log-log functional form (Friedl and Getzner 2003).

In Eq. (6), the study primarily assessed whether the past values of each predictor variable significantly improve the forecasting of CO₂ emissions. By applying the Pairwise Dumitrescu–Hurlin panel causality tests to data from Middle Eastern and BRICS countries, this study aims to uncover significant causal relationships that adhere to the following outlined hypotheses:

H1: Testing whether RE homogeneously causes CO₂ emissions:

$$\ln CO_{2i,t} = \alpha_i + \sum_{k=1}^p \beta_{1i,k} \ln CO_{2i,t-k} + \sum_{k=1}^p \beta_{2i,k} \ln RE + \varepsilon_{i,t} \tag{7}$$

H₀: RE_{t-k} does not homogeneously cause CO_{2,t}

H2: Testing whether EC homogeneously causes CO₂ emissions:

$$\ln CO_{2i,t} = \alpha_i + \sum_{k=1}^p \beta_{1i,k} \ln CO_{2i,t-k} + \sum_{k=1}^p \beta_{2i,k} \ln EC_{i,t-k} + \varepsilon_{i,t} \tag{8}$$

H₀: EC_{t-k} does not homogeneously cause CO_{2,t}

H3: Testing whether FDI homogeneously causes CO₂ emissions:

$$\ln CO_{2i,t} = \alpha_i + \sum_{k=1}^p \beta_{1i,k} \ln CO_{2i,t-k} + \sum_{k=1}^p \beta_{2i,k} \ln FDI_{i,t-k} + \varepsilon_{i,t} \tag{9}$$

H₀: FDI_{t-k} does not homogeneously cause CO_{2,t}

H4: Testing whether TO homogeneously causes CO₂ emissions:

$$\ln CO_{2i,t} = \alpha_i + \sum_{k=1}^p \beta_{1i,k} \ln CO_{2i,t-k} + \sum_{k=1}^p \beta_{2i,k} \ln TO_{i,t-k} + \varepsilon_{i,t} \tag{10}$$

H₀: TO_{t-k} does not homogeneously cause CO_{2,t}

The null hypothesis (default assumption) for every examination is that the respective variable fails to homogeneously cause CO₂ emissions.

To determine whether CO₂ emissions Granger-cause each independent variable, the study performed separate tests for CO₂ emissions against each independent variable. The hypothesis tests and equations represent that CO₂ emissions Granger-cause each independent variable, and the study analysis can be formulated as follows:

H5: Testing whether CO₂ emissions homogeneously cause RE:

$$\ln RE_{i,t} = \alpha_i + \sum_{k=1}^p \beta_{1i,k} \ln RE_{i,t-k} + \sum_{k=1}^p \beta_{2i,k} \ln CO_{2i,t-k} + \varepsilon_{i,t} \tag{11}$$

H₀: CO_{2,t} does not homogeneously cause RE_{t-k}

H6: Testing whether CO₂ emissions homogeneously cause EC:

$$\ln EC_{i,t} = \alpha_i + \sum_{k=1}^p \beta_{1i,k} \ln EC_{i,t-k} + \sum_{k=1}^p \beta_{2i,k} \ln CO_{2i,t-k} + \varepsilon_{i,t} \tag{12}$$

H₀: CO_{2,t} does not homogeneously cause EC_{t-k}

H7: Testing whether CO₂ emissions homogeneously cause FDI:

$$\ln FDI_{i,t} = \alpha_i + \sum_{k=1}^p \beta_{1i,k} \ln FDI_{i,t-k} + \sum_{k=1}^p \beta_{2i,k} \ln CO_{2i,t-k} + \varepsilon_{i,t} \tag{13}$$

H₀: CO_{2,t} does not homogeneously cause FDI_{t-k}

H8: Testing whether CO₂ emissions homogeneously cause TO:

$$\ln TO_{i,t} = \alpha_i + \sum_{k=1}^p \beta_{1i,k} \ln TO_{i,t-k} + \sum_{k=1}^p \beta_{2i,k} \ln CO_{2i,t-k} + \varepsilon_{i,t} \tag{14}$$

H₀: CO_{2,t} does not homogeneously cause TO_{t-k}

To investigate the robustness of the model, this study incorporated Panel DOLS. Panel DOLS is a statistical technique employed to estimate relationships in panel data with dynamic components (Addis and Cheng, 2023; Danish and Ulucak 2021; Thi et al. 2023). This method is particularly valuable for assessing the robustness of findings across different model specifications.

Drawing on the data presented and the arguments put forth by several researchers (Addis and Cheng, 2023; Alam and Murad 2020; Liu et al. 2022), this study examines the robustness of the study model. Similarly, this study conducted a thorough examination of the long-term relationships between RE, EC, FDI, TO, and CO₂ emissions in Middle Eastern and BRICS countries from 1995 to 2020. A study leveraging Panel DOLS estimation, which originated from academic contributions in the early 1990s and later expanded (Saikkonen 1992; Stock and Watson 1993; Kao and Chiang 2004), highlights this approach as a useful corrective to the FMOLS technique (Mark and Sul 2003). DOLS offers consistent estimations of standard errors (Addis and Cheng, 2023; Kao and Chiang 2004; Ugrinowitsch et al. 2004).

Empirical results and discussions

Descriptive statistics. The descriptive statistics for economic indicators are conducted for both Middle Eastern and BRICS countries in Tables 3 and 4, respectively. The results for Middle Eastern countries reveal notable trends and variations. The average values indicate that LnTO is the highest (mean = 4.41), while LnRE is the lowest (mean = 1.12). Data variability is moderate, with standard deviations ranging from 0.24 (LnEC) to 1.18 (LnCO₂), suggesting substantial fluctuations in CO₂ emissions and trade. Skewness values show that LnRE (0.95) and LnFDI (0.75) are positively skewed, indicating a small number of countries with high values, while LnTO exhibits extreme negative skew (−8.76). Additionally, kurtosis values are significantly high for LnEC (46.63) and LnTO (97.98), reflecting a pronounced peak and concentration of values around the mean. The Jarque–Bera test confirms significant deviations from normality (*p* < 0.001) for all indicators, underscoring the complexity of the dataset, which

Table 3 Descriptive statistics of variables for Middle Eastern countries.

	LnCO ₂	LnRE	LnEC	LnFDI	LnTO
Mean	2.056509	1.119063	3.956040	2.494923	4.413669
Median	2.227392	0.832909	3.979561	2.436482	4.483089
Maximum	3.864029	2.541602	4.712741	3.676809	5.256831
Minimum	−1.1759	0.6931	1.3873	1.6971	−3.8632
Std. Dev.	1.1827	0.5124	0.2387	0.2694	0.7349
Skewness	−0.5321	0.9497	−4.5052	0.7540	−8.7569
Kurtosis	2.4509	2.5780	46.6271	4.9817	97.9822
Jarque-Bera	18.6437	49.2182	25798.75	80.6203	121268.7
Probability	0.0000	0.0000	0.0000	0.0000	0.0000
Sum	641.6308	349.1477	1234.2850	778.4159	1377.0650
Sum Sq. Dev.	435.0666	81.6839	17.7258	22.5802	167.9852
Observations	312	312	312	312	312

Table 4 Descriptive statistics of variables for BRICS countries.

	LnCO ₂	LnRE	LnEC	LnFDI	LnTO
Mean	1.3495	2.7979	2.4937	0.5693	3.6905
Median	1.6808	2.8564	2.5547	0.6880	3.8213
Maximum	2.4748	3.9120	3.2961	1.6805	4.2397
Minimum	−0.2676	1.1631	1.3226	−1.5841	2.7495
Std. Dev.	0.8726	0.9713	0.3482	0.7363	0.3484
Skewness	−0.2502	−0.4598	−0.9333	−0.5995	−0.7428
Kurtosis	1.5948	1.7894	4.4493	2.5421	2.6355
Jarque-Bera	12.0523	12.5181	30.2529	8.9226	12.6757
Probability	0.0024	0.0019	0.0000	0.0115	0.0017
Sum	175.4450	363.7322	324.1866	74.0095	479.7747
Sum Sq. Dev.	98.2272	121.7147	15.6415	69.94770	15.6663
Observations	130	130	130	130	130

consists of 312 observations. These findings highlight the diverse economic landscape in the region and the need for careful interpretation in policy and economic planning.

The descriptive statistics for economic indicators in BRICS countries reveal important insights into regional trends. The average $\ln CO_2$ stand at 1.35, while $\ln RE$ is higher at 2.80, suggesting a reliance on renewables. $\ln FDI$ remains low at 0.57. The median values generally align with the means, indicating a symmetrical distribution. Standard deviations highlight variability, particularly in $\ln RE$ (0.97) compared to the more stable $\ln EC$ (0.35). Negative skewness across all variables suggests that most countries exhibit below-average values, especially in $\ln EC$ (-0.93) and $\ln FDI$ (-0.60). The kurtosis values indicate that $\ln CO_2$ and $\ln RE$ have flatter distributions, while $\ln EC$ shows a peaked distribution. Finally, the Jarque-Bera test confirms significant deviations from normality for all indicators ($p < 0.05$), emphasizing the complexity of the data. With 130 observations, these findings underscore the varied economic landscape of the BRICS and the need for nuanced interpretation in policy-making.

Furthermore, the analysis of average data from 1995 to 2020 for 17 countries in this study reveals substantial relationships and trends among the examined variables. CO_2 emissions vary remarkably across the countries examined, with Qatar ranking highest at 3.666 metric tons, followed closely by Kuwait at 3.212 and Bahrain at 3.098. These nations' heavy dependence on fossil fuels for energy production is indicative of economies driven primarily by the oil and gas sectors. In contrast, India has the lowest CO_2 emissions at just 0.156 metric tons, reflecting a relatively lower level of industrialization than other major economies in the dataset. Brazil also has low CO_2 emissions at 0.649 metric tons, largely attributed to its significant reliance on renewable energy sources, particularly hydropower. Figure 3 articulates how CO_2 emissions differ across BRICS and Middle East countries.

The consumption of renewable energy varies considerably among the countries studied, with Brazil leading at a renewable energy share of 3.809, supported by extensive utilization of

hydropower and biofuels. India follows closely with a renewable energy consumption figure of 3.691, highlighting its growing investments in solar and wind energy projects. Conversely, Gulf Cooperation Council (GCC) countries, including Qatar (0.725), Kuwait (0.701), Oman (0.695), Saudi Arabia (0.695), and Bahrain (0.693), demonstrate minimal reliance on renewable energy due to their abundant fossil fuel reserves. Figure 4 presents the trend of renewable energy usage from 1995 to 2020 for each country.

The per capita GDP serves as a critical indicator of economic development levels across countries. High-income nations such as Qatar (10.731), the UAE (10.515), Kuwait (10.266), and Israel (10.222) dominate this category, displaying robust economic metrics. In contrast, developing economies such as Yemen (6.665) and India (6.799) report significantly lower per capita GDP figures. Brazil's per capita GDP of 8.781 positions it as an emerging market economy, indicative of its ongoing development trajectory. Figure 5 shows the trend of GDP per capita from 1995 to 2020 for each country.

Key observations from the data indicate that countries with high CO_2 emissions, such as Qatar, Kuwait, the UAE, and Saudi Arabia, generally exhibit low renewable energy usage but maintain high per capita GDPs due to their dependence on fossil fuels for economic growth. Brazil is distinguished by its combination of low CO_2 emissions and high renewable energy consumption, illustrating a more sustainable development model than emerging economies such as India and China, which contradicts the work of (Addis 2025). Furthermore, trade openness is notably high among Gulf Cooperation Council (GCC) nations, driven by hydrocarbon exports. While India is a significant global economic player, its relatively low per capita GDP underscores the potential for growth, particularly in the realm of renewable energy adoption.

Diagnostic tests. This study utilized a correlation matrix alongside the Variance Inflation Factor (VIF) test to investigate the presence of multicollinearity among independent variables in a multiple regression model (Kim 2019). Multicollinearity occurs when two or more predictor variables exhibit a high degree of

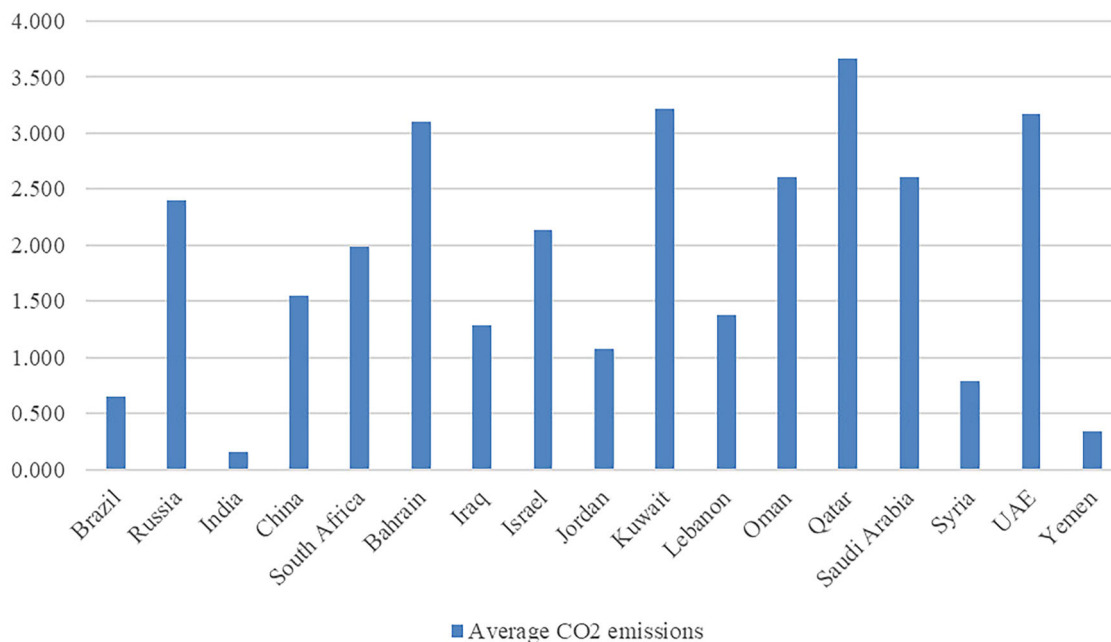


Fig. 3 Comparative CO₂ emissions: BRICS vs Middle East, (1995-2020). This clustered column chart compares CO₂ emissions across BRICS countries and selected Middle Eastern nations from 1995 to 2020. Each column represents the total CO₂ emissions (measured in metric tons) for each country during this period, providing a visual means to analyze both disparities and trends between these two regions.

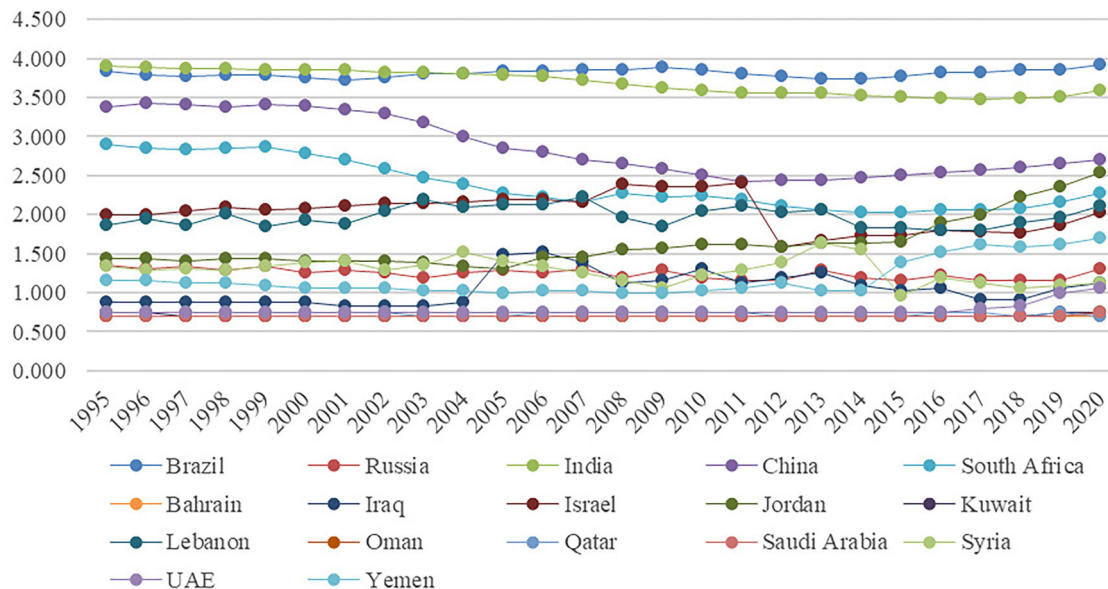


Fig. 4 Trends in renewable energy utilization, (1995–2020). This line chart illustrates the trends in renewable energy usage across BRICS nations compared to selected Middle Eastern countries from 1995 to 2020. It enables a comparative analysis of the strategies adopted by these regions to embrace renewable energy, reflecting a broader context of global energy transitions. The data highlights the differing rates of progress toward renewable energy goals and their implications for sustainable development moving forward.

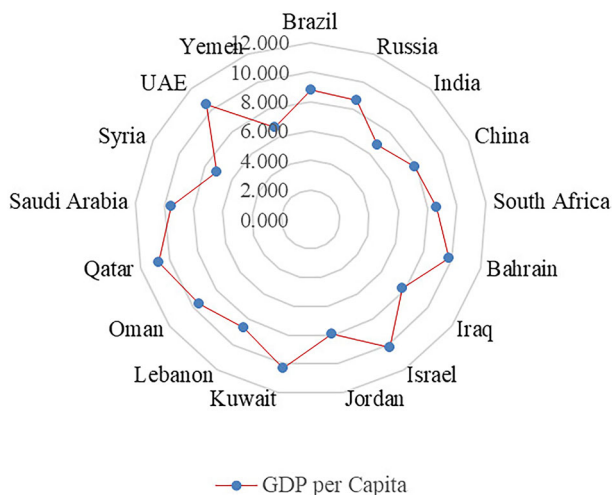


Fig. 5 Trends in average GDP per capita, (1995–2020). This radar chart portrays the average GDP per capita trends for BRICS countries in comparison to selected Middle Eastern nations over the period from 1995 to 2020. Each axis of the chart corresponds to the average GDP per capita (in USD) for the respective countries. This visualization allows for an immediate comparison of economic performance across the two regions, providing critical insights into their economic health, development policies, and long-term sustainability challenges.

correlation, indicating a strong linear relationship that complicates the isolation of each variable’s individual contribution to the dependent variable (Gurung 2024; Mahmood 2024). Such inter-correlation diminishes the unique informational value of these variables within the regression analysis, potentially undermining the integrity of the results. The presence of multicollinearity can lead to unreliable and unstable estimates of regression coefficients, inflated standard errors, and diminished statistical power, ultimately affecting the robustness of the study’s conclusions (Kim 2019; Vatcheva et al. 2016).

Table 5 Correlation matrix for Middle East countries.

	LnCO ₂	LnRE	LnEC	LnFDI	LnTO
LnCO ₂	1				
LnRE	-0.5324	1			
LnEC	0.2451	-0.1379	1		
LnFDI	0.1047	0.3169	0.0853	1	
LnTO	0.2445	-0.1434	0.1286	0.2006	1

Table 6 Correlation matrix for BRICS countries.

	LnCO ₂	LnRE	LnEC	LnFDI	LnTO
LnCO ₂	1				
LnRE	-0.9276	1			
LnEC	-0.3463	0.3632	1		
LnFDI	-0.0895	0.1863	0.1571	1	
LnTO	0.6710	-0.7094	-0.1075	-0.1063	1

The correlation matrices shown in Tables 5 and 6 for Middle Eastern and BRICS countries, respectively, provide insights into the relationships among key economic and environmental variables, highlighting both similarities and differences. In the Middle East, LnCO₂ emissions are negatively correlated with LnRE (-0.5324), indicating that increased renewable energy adoption is associated with lower emissions. However, this correlation is not as strong as the LnCO₂ emissions and renewable energy relationship in the BRICS countries, where the correlation is significantly stronger at -0.9276, suggesting a robust inverse relationship (Addis and Cheng, 2023).

In the Middle East, LnCO₂ exhibits a positive correlation with LnEC (0.2451), indicating that higher energy consumption may drive emissions (Arouri et al. 2012; Menyari 2024), while BRICS countries show a moderate negative correlation with LnEC (-0.3463), suggesting more efficient energy use in relation to emissions (Addis and Cheng, 2023).

Table 7 Variance Inflation Factor (VIF) test results for Middle Eastern and BRICS countries.

Variable	Middle Eastern		BRICS	
	Coefficient variance	Uncentered VIF	Coefficient variance	Uncentered VIF
LnRE	0.012879	1.046562	0.008960	1.216915
LnEC	0.005904	1.045685	0.004439	1.039049
LnFDI	0.010108	1.026676	0.001347	1.154367
LnTO	0.001277	1.022887	0.013410	1.399616

Furthermore, LnFDI in the Middle East shows a weaker correlation with LnCO₂ (0.1047) compared to the BRICS correlation of -0.0895, which indicates minimal influence of LnFDI on emissions in both regions. The study is supported by (Addis and Cheng, 2023) and (Arouri et al. 2012). Trade openness in the Middle East has a positive correlation with LnCO₂ (0.2445) and a negative correlation with LnRE (-0.1434), whereas in BRICS, LnTO is strongly positively correlated with LnCO₂ (0.6710) and negatively correlated with LnRE (-0.7094). Similar studies elsewhere corroborated this finding (Menyari 2024; Selmey et al. 2024). This indicates that increased trade is associated with higher emissions in the BRICS context, potentially due to fossil fuel reliance in trade activities. Generally, while both regions demonstrate notable relationships between renewable energy and emissions, the BRICS countries exhibit stronger correlations, particularly emphasizing the effective role of renewable energy in emissions reduction compared to the Middle Eastern countries, where relationships are generally weaker and more varied.

The VIF is a well-established diagnostic tool employed to identify multicollinearity by quantifying the extent to which the variance of a regression coefficient increases due to linear dependence among independent variables (Kim 2019; Vatcheva et al. 2016). The VIF results shown in Table 7 for both Middle Eastern and BRICS countries demonstrate low multicollinearity among predictor variables in their respective regression models. In the Middle Eastern context, LnRE has a VIF of 1.0466, while LnEC follows closely with a VIF of 1.0457. LnFDI is reported at 1.0267, and LnTO shows a VIF of 1.0229. All these values are well below the threshold of 5, confirming the independence of the variables, thus ensuring reliable interpretation of regression coefficients.

In contrast, the BRICS countries display slightly higher VIF values: LnRE stands at 1.2169, LnEC at 1.0390, LnFDI at 1.1544, and LnTO at 1.3996. Although these values indicate low multicollinearity, they are higher than those observed in the Middle Eastern countries. Nevertheless, all BRICS VIF values remain below the critical threshold, suggesting that, like in the Middle East, the regression coefficients can be interpreted reliably. This consistency across both datasets allows for dependable assessments of the relationships among the predictor variables within each economic context.

Cross-sectional dependence (CD) test. The CD test indicates interdependence among cross-sectional units in a dataset, which is crucial when studying various econometric variables that could influence one another. Assessing CD before unit root and cointegration tests is vital for accurate statistical analysis (Addis and Cheng, 2023; Pesaran 2004; Tugcu 2018). CD tests help ensure reliability and validity, which are pivotal in panel data analysis. It detects cross-sectional correlations in regression errors, highlighting interdependence across regions or variables with social, environmental, or economic spillover effects (Menegaki 2020). Understanding CD aids in choosing appropriate panel unit root

Table 8 Results of the CD test for Middle Eastern and BRICS countries.

Test	Middle Eastern			BRICS		
	Statistic	d.f.	P-value	Statistic	d.f.	P-value
Breusch-Pagan LM	175.9248	66	0.0000	95.1653	10	0.0000
Pesaran scaled LM	9.5677		0.0000	19.043		0.0000
Pesaran CD	-3.3241		0.0009	-3.2066		0.0013

tests, factoring in variables such as geographical spillovers and omitted factors. The presumption is that the residuals from the panel data regression lack interdependence (Chandio et al. 2022). Researchers have identified strong and weak forms of CD, emphasizing its impact on cross-country studies (Deistler et al. 2010).

Three popular CD tests were conducted in this study, and these tests are designed to determine whether the error terms over numerous units are correlated, which might have major implications for the validity of statistical inference and model estimation. For example, (i), the Breusch-Pagan Lagrange multiplier (LM) test, is a typical test for determining the presence of CD (Breusch and Pagan 1980). It uses likelihood ratio assessment to ascertain whether the error components in a regression model are associated among different cross-sectional units. A significant Breusch-Pagan LM test statistic indicates the presence of CD.

(ii) The Pesaran scaled Lagrange multiplier (LM) test serves as a modification of the Breusch-Pagan LM test that tackles heteroskedasticity and autocorrelation potential issues (Pesaran 2004). To accommodate these difficulties, it adjusts the test statistic by scaling the residuals, resulting in a more robust test for CD. When the Pesaran adjusted LM test statistic is significant, it suggests the existence of CD. (iii) The Pesaran CD test, which integrates the Breusch-Pagan LM test with the Pesaran-scale LM test into a single statistic, is a prominent test for CD (Pesaran 2004). It is derived from the combination of the Breusch-Pagan LM test statistic and the Pesaran scaled LM test statistic. Because it considers both the presence of cross-sectional reliance and possible concerns with heteroskedasticity and autocorrelation, this combined statistic provides a stronger test for CD. If the Pesaran CD test result is significant, it implies that the CD exists.

Therefore, these three popular tests were conducted to summarize the CD test results for all the variables examined in the study from 1995 to 2020 for both Middle Eastern and BRICS countries, as presented in Table 8. The null hypothesis for the CD tests asserts that there is no CD (correlation) among the residuals, indicating that they are independent of one another. Conversely, the alternative hypothesis suggests that a CD exists within the residuals.

Table 8 illustrates that the null hypothesis is decisively rejected for all variables, according to the calculated *p*-values. This indicates significant evidence of interdependence among the

Table 9 Results of the CIPS and CADF Unit Root Tests (Second Generation) for Panel Data in Middle Eastern and BRICS Countries.

Test	Middle Eastern				BRICS			
	CIPS		CADF		CIPS		CADF	
	t-statistic	t-statistic	t-statistic	t-statistic	t-statistic	t-statistic	t-statistic	t-statistic
Variables	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
LnCO ₂	1.176	-3.921*	1.076	-9.924**	-0.552	-2.403**	-0.574	-3.495***
LnRE	1.124	-2.551**	0.568	-4.752**	-1.672**	-1.737***	-1.693**	-3.422***
LnEC	-7.461*	-1.571**	-6.763*	-2.689***	-4.445*	-3.413**	-3.909	-5.885**
LnFDI	-3.913*	-1.632**	-3.721*	-2.771**	-2.460	-2.548**	-3.477*	-3.329***
LnTO	-1.671**	-2.827*	-1.441	-2.324***	-0.151	-2.906***	-0.074	-2.681**

Note: *, **, and *** indicate the significance levels of 1%, 5%, and 10%, respectively.

Table 10 Westerlund panel cointegration test result.

Statistics	Middle Eastern		BRICS	
	Value	P-value	Value	P-value
LnRE	-1.4470	0.0000	-0.6216	0.0000
LnEC	0.0372	0.8822	0.0474	0.7881
LnFDI	1.2009	0.0042	0.1371	0.0820
LnTO	0.1212	0.4937	0.7848	0.0000

variables across countries. This phenomenon can be attributed to various factors, including external shocks, economic ties, or common policies. Consequently, any unexpected change in Middle Eastern or BRICS nations may influence the behavior of member countries, highlighting a possible interconnectedness in their environmental or economic dynamics.

The study results are consistent with those of Al-mulali (2011) in Middle Eastern nations and Author (2023b) and Baloch et al. (2022) in BRICS countries. Consequently, this study can advance with assessment and estimation methods that consider CD, including the panel data unit root test. It can be used in conjunction with CD tests to obtain more robust results and better control for potential biases arising from CD.

Panel unit root test. After conducting the CD test, the next step is to perform a panel data unit root test to evaluate the stationarity of the variables involved. This study identified the presence of CD; failing to account for it may result in biased outcomes and erroneous conclusions in panel unit root tests (Naqvi et al. 2022). When CD is identified in panel data, traditional first-generation unit root tests, such as the LLC (Levin-Lin-Chu) (Levin et al. 2002), (IPS) Im-Pesaran-Shin (Im et al. 2003), (ADF) augmented Dickey-Fuller (Dickey and Fuller 1979), and (PP) Fisher chi-square tests (Phillips and Perron 1988) tests, which rely on the assumption of cross-sectional independence, may yield unreliable results. Consequently, it becomes essential to employ second-generation panel unit root tests that are explicitly designed to address the effects of CD (Pesaran 2007). Notable examples of these advanced tests include Pesaran’s Cross-sectionally Augmented IPS (CIPS) test and the Cross-sectionally Augmented Dickey-Fuller (CADF) test, both developed by Pesaran (2007). These methodologies enhance the robustness of the analysis by appropriately modeling the dependence across cross-sections, thereby improving the accuracy of inference in panel data contexts (Rana et al. 2024).

Unit root analysis is essential for identifying whether a variable is stationary or nonstationary (Tugcu 2018). The results shown in

Table 9 revealed nonstationarity at levels, but stationarity at first differences, indicating no unit root. Consequently, the regression analysis can proceed at first differences, demonstrating that the model’s first differences for both country groups are stationary.

The CIPS test results show that in BRICS, LnRE and LnEC are the only significant variables at level, while in the Middle East, only LnEC, LnFDI, and LnTO are significant. CADF test results indicate that most variables have insignificant *p*-values, except for specific cases in both regions. Notably, all variables have significant *t*-statistics at the first difference. The study observed that both tests yielded similar results at the first difference, while at the level, they produced differing conclusions regarding stationarity. Generally, the findings from both tests present a mixed picture of stationarity for the entire panel, prompting a transition to the next phase of analysis, which involves panel cointegration.

Panel cointegration test. The panel cointegration analysis is based on the notion of cointegration introduced by econometrician (Engle and Granger 1987). It aims to identify cointegrating relationships among the variables across different cross-sectional units, allowing conclusions to be drawn about the long-term equilibrium connections among variables (Granger 1986). Cointegration methods have garnered significant interest for assessing the presence of long-term equilibrium relationships among nonstationary time series variables (Addis and Cheng, 2023; Pedroni 2001; Westerlund 2007). In other words, if multiple variables exhibit cointegration, it implies a stable long-run nexus among them, despite potential short-run trend differences.

This study conducted the Westerlund panel cointegration test, a second-generation panel cointegration tests. It is a robust method used to determine if a long-run equilibrium relationship exists among nonstationary time series data in a panel setting. Unlike first-generation panel cointegration tests like Pedroni residual cointegration test (Pedroni 2004), Kao residual cointegration test (Kao 1999), and Johansen Fisher panel cointegration test (Johansen 1988), the Westerlund test (Westerlund 2007), accounts for cross-sectional dependence, which is a common feature in macroeconomic panel data. Table 10 illustrates the Westerlund panel cointegration test results for Middle East and BRICS countries.

The Westerlund panel cointegration test results for the key variables—RE, EC, FDI, TO, and CO₂ emissions—reveal important differences between the Middle Eastern and BRICS regions. Both regions show significant cointegration for renewable energy, with statistics of -1.4470 (*p*-value 0.0000) for the Middle East and -0.6216 (*p*-value 0.0000) for BRICS, suggesting that renewable energy strongly influences other economic indicators (Balli et al. 2023; Iqbal et al. 2023). Conversely, energy

Table 11 Pairwise Dumitrescu-Hurlin panel causality tests for Middle Eastern and BRICS countries (1995–2020).

Null hypothesis	Middle Eastern			BRICS		
	W-Stat.	Zbar-Stat.	Prob.	W-Stat.	Zbar-Stat.	Prob.
LNRE does not homogeneously cause LNCO ₂	4.7986	3.057	0.0022	7.6694	4.829	1.E–06
LNCO ₂ does not homogeneously cause LNRE	3.7072	1.755	0.0792	1.4095	–0.734	0.4630
LNEC does not homogeneously cause LNCO ₂	2.2369	0.002	0.9985	2.0228	–0.189	0.8502
LNCO ₂ does not homogeneously cause LNEC	2.0776	–0.188	0.8508	4.9665	2.428	0.0152
LNFDI does not homogeneously cause LNCO ₂	2.7257	0.585	0.5587	2.8487	0.545	0.5856
LNCO ₂ does not homogeneously cause LNFDI	6.0679	4.570	5.E–06	3.3197	0.964	0.3351
LNTO does not homogeneously cause LNCO ₂	9.1987	8.304	0.0000	2.5611	0.289	0.7721
LNCO ₂ does not homogeneously cause LNTO	3.4554	1.455	0.1457	7.9878	5.113	3.E–07

consumption lacks significance in both regions, indicating a weak relationship with the other variables (Balli et al. 2023). FDI shows significant cointegration in the Middle East, but only hints at a relationship in BRICS (*p*-value 0.0820) (Ahmad et al. 2020; Doytch et al. 2024). Studies elsewhere corroborated this finding (Azam and Haseeb 2021; Balli et al. 2023). Additionally, trade openness reveals contrasting effects, being insignificant in the Middle East while exhibiting strong significance in BRICS (Ofori et al. 2024). These findings highlight the necessity for region-specific policies focused on renewable energy and FDI to foster sustainable economic growth.

Panel causality test. Before performing the panel causality analysis, it is crucial to first verify the findings of a panel data unit root test to ensure that the study data meet stationarity requirements and do not contain any unit roots at first differences. This step helps eliminate potential issues with autocorrelation and skewness in the analysis. Findings from the panel cointegration and unit root tests indicate that the model shows the presence of long-term equilibrium relationships, is free from unit roots, and is stationary. Consequently, this study can confidently proceed with the necessary testing and estimation methods required for panel causality analysis, specifically Pairwise Dumitrescu–Hurlin panel causality tests, to further understand the causal associations between CO₂ emissions and the relevant variables under consideration. Its test outcomes are described in terms of *p*-values and confidence intervals, which indicate the statistical significance and strength of the relationships among the variables.

Table 11 summarizes the results of pairwise Dumitrescu–Hurlin panel causality tests conducted on logarithmic transformations of economic and environmental variables for the Middle Eastern and BRICS countries from 1995 to 2020. In Middle Eastern countries, the analysis reveal significant findings regarding the causal links among these variables. Firstly, the tests indicate a significant unidirectional causality from LnRE to LNCO₂, with a *W*-statistic of 4.7986 and a *p*-value of 0.0022. This strong relationship suggests that increasing renewable energy consumption in Middle Eastern countries contributes to a reduction in CO₂ emissions, supporting the hypothesis that transitioning to renewable energy is an effective strategy for mitigating environmental impacts. Consequently, the study hypothesis that LnRE does not homogeneously cause LNCO₂ (i.e., H1) can be rejected based on the significant unidirectional causality observed in the results (Addis and Cheng, 2023). Specifically, the tests indicate strong evidence that increasing renewable energy utilization effectively reduces carbon emissions, especially pronounced in the BRICS nations (Zakarya et al. 2015).

Conversely, the causality from LNCO₂ to LnRE is not robustly established, with a *W*-statistic of 3.7072 and a marginal *p*-value of 0.0792, indicating a weak potential influence of carbon emissions

on renewable energy consumption decisions. The second part of this hypothesis (H5), that LNCO₂ does not homogeneously cause LnRE, is supported by the findings showing significant causality in Middle East: 0.0792, but not significant in BRICS: 0.4630. This indicates that fluctuations in CO₂ emissions do not significantly influence decisions around renewable energy consumption, revealing a one-directional relationship where renewable energy efforts primarily affect CO₂ emissions rather than being driven by them.

Moreover, the results indicate no significant causal relationship between LnEC and LNCO₂, as shown by a *p*-value of 0.9985 and 0.8502 in Middle East and BRICS, respectively. This suggests that fluctuations in energy consumption do not significantly impact carbon emissions in either region. The study’s result contradicts the findings of Al-mulali (2011) for Middle Eastern and supported by Selmeý et al. (2024) in BRICS countries. The hypothesis (H2) that LnEC does not homogeneously cause LNCO₂ was not rejected. The second part of this hypothesis (H6), that LNCO₂ does not homogeneously cause LnEC, shows significant causality in BRICS (0.0152), supported by (Ofori et al. 2024; Selmeý et al. 2024), but not in the Middle East (0.8508), which contradict (Akadiri and Akadiri 2020; Gorus and Aydin 2019).

In the BRICS countries, analysis found no significant causal relationship between LnFDI and LNCO₂, with *p*-values of 0.5856 and 0.3351 (Shaari et al. 2014). In contrast, data from Middle Eastern nations indicated a strong unidirectional causality from LNCO₂ to LnFDI, with a *p*-value of 5.0E–06. This suggests that higher CO₂ emissions deter FDI, implying that investors may avoid markets with significant pollution (Gök et al. 2024). Moreover, FDI does not appear to directly affect CO₂ emissions, likely due to investor preferences for non-environmentally impactful sectors. Factors such as the type of FDI, the host country’s economic development, and existing environmental regulations also play critical roles. The hypothesis (H3) suggesting that LnFDI does not causally influence LNCO₂ is supported across both regions. However, H7 shows that LNCO₂ significantly negatively impacts LnFDI in the Middle East, indicating that environmental concerns influence investment decisions more strongly in that region compared to BRICS. This underscores the need for effective regulatory frameworks to mitigate emissions and foster investment.

Additionally, in Middle Eastern countries, a strong causal relationship exists between LNTO and LNCO₂, with a *p*-value of 0.0000. This indicates that increased trade openness correlates with rising carbon emissions, reflecting the environmental costs associated with expanding trade activities (Gava et al. 2025; Menyari 2024). Conversely, the reverse causation from LNCO₂ to LNTO is not significant (*p*-value: 0.1457), suggesting that carbon emissions do not directly influence trade openness in this context.

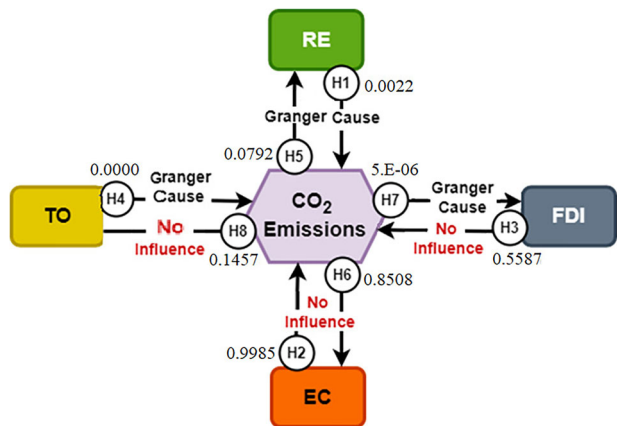


Fig. 6 Pairwise Dumitrescu-Hurlin panel causality findings and hypothesis testing with their p-values for Middle Eastern countries. This panel showcases the findings from the Dumitrescu–Hurlin causality test applied to assess the causal relationships between CO₂ emissions and several economic variables in Middle Eastern countries. The investigated variables include Renewable Energy (RE), Energy Consumption (EC), Foreign Direct Investment (FDI), and Trade Openness (TO). Results are depicted alongside their corresponding for each hypothesis tested. Significant (typically $p < 0.05$) suggest a causal relationship, while nonsignificant indicate a lack of such evidence. This clear presentation of hypotheses and outcomes provides meaningful insights into the interplay between CO₂ emissions and the selected economic factors, highlighting potential areas for policy intervention and further investigation.

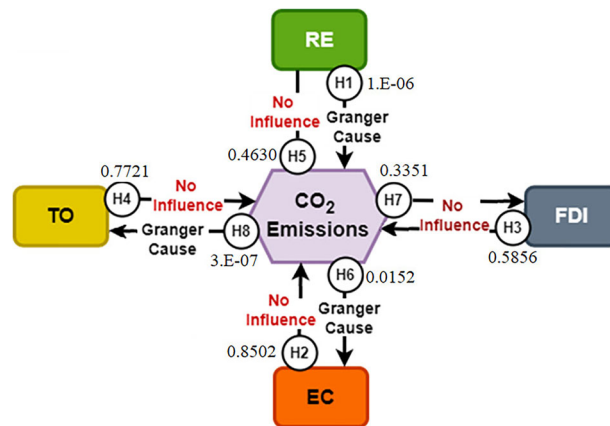


Fig. 7 Pairwise Dumitrescu-Hurlin panel causality findings and hypothesis testing with their p-values for BRICS nations. This summarizes the outcomes of the Dumitrescu–Hurlin causality test, analyzing eight hypotheses that investigate the causal relationships between CO₂ emissions and several economic variables in BRICS nations. The key variables scrutinized include Renewable Energy (RE), Energy Consumption (EC), Foreign Direct Investment (FDI), and Trade Openness (TO). Each hypothesis is listed alongside its corresponding p-value, allowing for easy identification of significant relationships. A significant ($p < 0.05$) indicates evidence of a causal relationship, whereas a non-significant suggests a lack of such evidence. This overview facilitates straightforward comparison of the causal dynamics among the examined variables, offering crucial insights for policymakers and scholars interested in energy and economic interdependencies within BRICS countries.

In BRICS nations, LnCO₂ is found to cause LnTO, with a significant p -value of 3.E–07. This relationship suggests that rising CO₂ emissions may prompt changes in trade policies, reflecting how these countries could adapt to environmental challenges (Zhou et al. 2025). This finding was corroborated by (Addis and Cheng, 2023). No significant causality was observed from LnTO to LnCO₂ (p -value: 0.7721), challenging the findings of (Chhabra et al. 2023).

Hypothesis H4, positing that LnTO does not causally influence LnCO₂, is rejected for Middle Eastern countries due to the demonstrated significant association. This suggests that expanding trade may lead to increased carbon emissions, potentially indicating a lack of environmental consideration in trade policies (Menyari 2024). The weaker causation in BRICS necessitates further investigation, as varied economic structures may affect the environmental impact of trade. Additionally, hypothesis H8 shows significant causality from LnCO₂ to LnTO in BRICS, further indicating that increased emissions may drive trade adjustments (Chhabra et al. 2023; Selmeý et al. 2024).

Figures 6 and 7 illustrate the results of the panel causality analysis and hypothesis testing conducted for both Middle Eastern and BRICS nations.

Robustness check. Before conducting the robustness checks, this study ensures that the study data are stationary to reduce the risk of autocorrelation. It is crucial to confirm the order of integration, which is typically I(1), as this is crucial for developing robust econometric models, particularly when the DOLS estimation method is employed. Once the study has confirmed the existence of cointegration among the variables related to the Middle East and BRICS nations, it focuses on estimating the long-term interactions among these key variables.

Table 12 presents the outcomes of the panel cointegration analyses obtained through the panel DOLS weighted estimation technique for Middle Eastern and BRICS countries. The results of the Panel DOLS estimation of Middle Eastern countries,

Table 12 DOLS estimation model for Middle Eastern and BRICS countries.				
Variable	Middle Eastern		BRICS	
	Coefficient	P-value	Coefficient	P-value
LnRE	−0.2206	0.0019	−0.6644	0.0000
LnEC	0.5052	0.0121	0.1150	0.4567
LnFDI	0.1596	0.0107	0.0897	0.0067
LnTO	−0.1153	0.2636	0.3302	0.0005
R-squared	0.9923		0.9914	
Adjusted R-squared	0.9816		0.9786	

presented in Table 12, reveal that RE is significantly associated with CO₂ emissions. In particular, a unit increase in RE leads to a reduction in CO₂ emissions of 0.220%, underscoring the efficacy of renewable energy investments in combating climate change. Similar studies elsewhere supported this finding (Alharthi et al. 2021; Kahia et al. 2019). In contrast, elevated levels of EC and FDI inflows are linked to significant increases in CO₂ emissions of 0.505% and 0.159%, respectively, indicating the need for more sustainable and efficient energy practices.

Despite the insignificance, TO negatively impacts CO₂ emissions at 0.115%, and the analysis suggests that environmental considerations should be integrated within economic schemes to ensure stability between economic development and environmental preservation. Encouraging green investments and adopting eco-friendly trade policies could serve as avenues to diminish the negative implications of economic activities on the climate.

The findings for BRICS countries, shown in Table 12, reveal that all the examined variables, excluding EC, significantly influence CO₂ emissions, validating their long-term associations. Notably, a modest increase in RE causes a notable decline in CO₂

emissions of 0.664%, indicating its effectiveness in combating environmental pollution. Results from this study were corroborated by studies elsewhere (Mehta and Shah 2024). Conversely, a unit increase in FDI inflows and trade openness is linked to higher CO₂ emissions by 0.089% and 0.33%, respectively, underscoring the environmental costs of economic activities and globalization. Energy consumption, although its value is not significant, positively influences CO₂ emissions, and policymakers should interpret it cautiously.

The findings from the panel DOLS evaluation for Middle Eastern and BRICS countries highlight critical policy recommendations focused on reducing CO₂ emissions and addressing the climate crisis. A primary recommendation is the urgent advancement and implementation of sustainable energy strategies, complemented by initiatives to improve energy efficiency and decrease total energy consumption. Additionally, ensuring that FDI inflows comply with environmental sustainability principles and that trade policies favor green practices are essential steps toward achieving sustainable development goals in both regions.

While the panel DOLS results indicate promising pathways for minimizing the carbon footprint through the adoption of renewable energy, it remains crucial to assess and refine regulatory frameworks concerning FDI inflows and trade policies in both Middle Eastern and BRICS countries. This ongoing evaluation is vital for effectively adapting and optimizing pollution mitigation strategies. Overall, the findings from the robust model align well with those from the baseline models, with one notable exception: trade openness is not statistically significant in Middle Eastern countries, whereas energy consumption is not significant in BRICS countries.

Conclusions

This study undertakes a comparative analysis of Middle Eastern and BRICS countries to investigate the influencing factors of environmental pollution and the relationships among CO₂ emissions, renewable energy, FDI inflows, energy consumption, and trade openness. The study uses panel data methods, including the Westerlund panel cointegration test, the pairwise Dumitrescu–Hurlin panel causality test, robustness checks with DOLS model estimations, and other supportive statistical methods. This covers the period from 1995 to 2020. To address country-specific differences and biases, we use various econometric approaches. These include CD tests, CIPS tests, and CADF unit root tests. This framework improves the reliability of our findings. It ensures that the analysis accurately reflects the underlying dynamics across Middle Eastern and BRICS countries.

This study elucidates the distinct relationships between renewable energy and CO₂ emissions in the BRICS and Middle Eastern countries, finding stronger correlations in the BRICS nations. In particular, the findings of this study indicate that a unit increase in renewable energy leads to a 0.22% decrease in CO₂ emissions in the Middle East and more pronounced to reduction of 0.66% in BRICS. The disparity in reduction rates highlights varying levels of effectiveness, which could be attributed to several factors, including the existing energy infrastructure, the scale of renewable energy adoption, economic structure, and the specific economic and environmental policies in place within each region.

Additionally, although the BRICS countries show slightly higher VIF values than the Middle Eastern countries, both sets of values stay below the critical limit (threshold). This indicates that multicollinearity is not a major issue in our analysis, as both groups display low levels of dependence among the independent variables, ensuring the reliability of regression coefficient

interpretations. Moreover, the findings of the CD test indicate persistent long-run influences among member countries, necessitating the use of advanced second-generation panel unit root tests like the CIPS and CADF tests to avoid potential biases in unit root outcomes.

The results from the CIPS and CADF tests confirm the stationarity of variables, prompting an examination of long-term equilibrium relationships through the Westerlund panel cointegration test. Significant cointegration was observed in both regions for renewable energy, supporting its crucial role in influencing economic indicators (Alharthi et al. 2021; Tukhtamurodov et al. 2024). In contrast, energy consumption showed a weak correlation and was statistically insignificant, while FDI relationships differed between the regions (Tukhtamurodov et al. 2024). Tailored policy interventions focusing on renewable energy and FDI are vital for achieving sustainable economic growth.

The subsequent pairwise Dumitrescu–Hurlin panel causality tests reveal significant unidirectional causality from renewable energy consumption to CO₂ emissions in the Middle East, underscoring the environmental benefits of renewable energy adoption. Notably, fluctuations in energy consumption and FDI showed minimal impact on emissions, while higher emissions were found to deter FDI (Pham et al. 2025). Additionally, increased trade openness correlates positively with emissions, while the reverse relationship is negligible, indicating complex dynamics that necessitate further investigation (Gava et al. 2025; Pham et al. 2025).

The panel DOLS estimation results illustrate the relationships between CO₂ emissions, renewable energy, trade openness, FDI inflows, and energy consumption in the BRICS and Middle Eastern countries. In the BRICS context, all variables, except energy consumption, significantly influence CO₂ emissions, with a slight increase in renewable energy linked to reduced emissions (Addis and Cheng, 2023). Conversely, FDI inflows and trade openness are associated with increased emissions, reflecting the environmental costs of economic growth (Balli et al. 2023; Ofori et al. 2024). The study results indicate that increased investment may lead to higher emissions due to a focus on carbon-intensive sectors. For Middle Eastern nations, a statistically significant negative relationship between renewable energy and CO₂ emissions exists, although its impact (0.220%) is weaker than in the BRICS (Balli et al. 2023; Iqbal et al. 2023). Notably, both energy consumption and FDI correlate with substantial emissions increases, highlighting the urgent need for sustainable energy practices.

Both regions underscore the critical role of renewable energy in mitigating emissions (Addis and Cheng, 2023; Kahia et al. 2019). However, findings indicate that energy consumption has a more significant effect on CO₂ emissions in the Middle East than in BRICS countries due to its heavy reliance on fossil fuels for energy production (Balli et al. 2023; Tukhtamurodov et al. 2024). These findings underscore the vital importance of renewable energy in reducing emissions and highlight the differing environmental challenges faced by each region.

Policy recommendation and future research direction

This study findings highlight critical policy implications for reducing CO₂ emissions in Middle Eastern and BRICS economies, underscoring the pivotal role of renewable energy (RE), and the nuanced effects of energy consumption, trade openness, and foreign direct investment (FDI).

Prioritizing and promoting renewable energy investments. The literature is teeming with evidence that renewable energy

consumption has a negative effect on CO₂ emissions in BRICS and the Middle East (Akram et al. 2020; Khattak et al. 2020; Naqvi et al. 2022; Xu and Hussain 2023). In particular, the findings of this study indicate that a unit increase in renewable energy leads to a 0.22% decrease in CO₂ emissions in the Middle East and more pronounced to reduction of 0.66% in BRICS. This contrast implies different degrees of efficiency, perhaps influenced by energy infrastructure, policy environment, or the magnitude of renewable energy usage. Therefore, regional governments must develop robust policies that facilitate the accelerated deployment of renewable energy sources by implementing comprehensive financial incentives, including targeted subsidies, green credit mechanisms, and regulatory frameworks that support the development and integration of solar, wind, and hydropower projects, thereby contributing to emissions reductions and energy security (Jiang and Yuan 2025).

Additionally, policymakers should prioritize renewable energy investments while closely monitoring energy consumption patterns to improve energy efficiency. Given the weak correlation between FDI and CO₂ emissions, it is essential to attract investments in sustainable technologies and promote environmentally responsible industrial practices. Additionally, trade policies must incorporate environmental criteria, establishing import standards and incentivizing sustainable products in trade agreements.

The interactions among these variables underscore the need for cohesive policies that integrate economic growth, FDI, and environmental sustainability (Altouma et al. 2024; Cai et al. 2024). Governments should consider implementing carbon taxes, emissions trading systems, and renewable energy subsidies to facilitate the transition to cleaner technologies and reduce emissions (Zhang et al. 2023). Additionally, enhancing energy efficiency through building renovations and technological innovation is crucial for decreasing energy consumption and emissions (Jia et al. 2024). To achieve these goals, it is also important to adopt proactive resilience strategies that foster sustainable ecosystems in both digital and energy sectors. Furthermore, international cooperation and technology transfer initiatives are essential to assist developing countries in their shift to sustainable energy systems (Cheng et al., 2023; Ahmad et al. 2024). By aligning economic development with sustainability efforts, regions can work toward a cleaner, more resilient future.

Addressing the dynamics of energy consumption. In BRICS nations, energy consumption is strongly influenced by CO₂ emissions, meaning that an increase in emissions will stimulate energy demand, either for energy mitigation options or as a result of increased industrial activity that requires more energy (Akram et al. 2020; Khan et al. 2021). Such unidirectional causality is also a call for the decoupling of economic expansion from carbon-dependent energy consumption in which energy efficiency improvement and non-fossil fuel-based energy substitution should be the key solutions. In the case for Middle Eastern countries, this study reveals that there is no significant impact of energy consumption on CO₂ emissions and vice versa. This indicates that energy consumption is currently mainly non-fossil fuel based or that the size of energy consumption is not sufficient to cause an increase in CO₂ emissions, which is unlikely in this oil-producing region (To et al. 2019). Policy makers in both regions should continue to encourage efficiency to stretch resources and hedge against future changes in energy demand. Implementing stricter regulations on energy consumption in high-emission sectors in both regions is critical to fostering energy efficiency and technological advancement.

Re-evaluating the environmental impact of trade openness and FDI. The finding shows that trade openness has a unidirectional effect on CO₂ emissions in both regions. This highlights that increased trade, likely due to higher transportation and production, leads to higher emissions (Luo et al. 2022; Shahbaz et al. 2017). Policymakers should incorporate environmental impact assessments into trade agreements to promote green trade practices and provide subsidies for the import and export of eco-friendly technologies and goods, as corporate green innovation is essential for advancing sustainable development (Gao et al. 2025).

Moreover, the study finds that FDI shows no significant predictive power for emissions levels in either Middle Eastern or BRICS countries. This finding challenges the “pollution haven” or “pollution halo” hypotheses, suggesting that the impact of FDI on CO₂ emissions is not straightforward or uniformly negative or positive in these contexts (Demena and Afesorgbor 2020). Policymakers need to closely examine the types of FDI attracted, ensuring that foreign investments align with SDGs and promote green technologies instead of polluting industries. Encouraging sustainable FDI through guidelines that favor green initiatives can further reduce the environmental impact of industrial activities. Furthermore, raising public awareness and education about the benefits of renewable energy is crucial for gaining support for sustainable policies among citizens and businesses.

This study has several limitations that should be acknowledged. First, the analysis primarily relies on econometric data from specific time periods (1995–2020), which may not capture temporal variations and the full effects of contemporary policy changes on renewable energy adoption and CO₂ emissions in the Middle Eastern and BRICS economies. Second, the focus on aggregate indicators may oversimplify the complexities of regional dynamics and the interplay of other factors, such as technological advancements and local economic conditions, which can impact the effectiveness of renewable energy in reducing emissions. Finally, the study is constrained by the availability and quality of data, particularly in some Middle Eastern countries where data transparency may be limited.

Therefore, future research should aim to address these limitations by utilizing more granular data, including sector-specific analyses that can illuminate the roles of various economic sectors in emissions reduction efforts. Investigating the impact of governmental policies and incentives on renewable energy uptake across different regions would provide valuable insights into best practices. Incorporating a broader range of economic indicators, such as GDP growth, technological innovation, and energy efficiency, could enhance the robustness of the findings. Moreover, longitudinal studies extending beyond the current time-frame would help ascertain the long-term effects of renewable energy on CO₂ emissions.

Data availability

All data generated or analyzed during this study are included in this published article and its supplementary information files.

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AKA: Conceptualization, Methodology, Data Gathering, Data Curation, Software, Analysis, Validation, Original Draft, Writing-Reviewing, Proofreading.

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The author declares no competing interests.

Ethical approval

This study does not involve human or animal subjects.

Informed consent

This study does not involve human participants.

Additional information

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