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Climate Change, Decarbonization, and Energy Transition in Arab Countries: A Fresh Insight Using Panel Cointegration Approach

Sufian Eltayeb Abdel-Gadir *

Abstract

This study analyzes the progress of decarbonization in Arab countries by examining the interplay of various economic and governance factors. The model specification includes CO_2 emissions per capita, real GDP per capita, government effectiveness, financial development, renewable energy consumption, energy use, and the percentage of urban population as key variables. Using data from 1996 to 2022 within a panel data framework, econometric techniques were employed to investigate the long-term relationships among these variables. The findings are based on a panel dataset of 12 Arab countries, selected based on data availability. The study employs Canonical Cointegrating Regression (CCR), Fully Modified Least Squares (FMOLS), Dynamic Least Squares (DOLS), and Robust Least Squares to investigate the determinants of CO_2 emissions. The analysis reveals that energy use (ENUS), GDP per capita (GDPPC), government effectiveness (GVEF), and renewable energy (RENEN) significantly influence CO_2 emissions across different econometric methods. Robustness checks confirm the reliability of these results, highlighting the critical roles of these variables in understanding CO_2 emissions and the effectiveness of robust regression techniques in addressing potential outliers and enhancing model accuracy. Panel cointegration tests consistently demonstrate significant cointegration among the variables, indicating a long-term relationship between them. These findings provide valuable insights into the interconnected dynamics of economic growth, governance, energy consumption, urbanization, and CO_2 emissions in Arab countries. Understanding these relationships is crucial for policy formulation and sustainable development strategies in the region.

تغير المناخ، وخفض الكربون، والتحول للطاقة النظيفة في الدول العربية: رؤية جديدة باستخدام منهجية التكامل المشترك

سفيان الطيب عبد القادر

ملخص

تركز هذه الدراسة على تحليل التقدم المحرز في خفض الكربون في الدول العربية من خلال دراسة التفاعل بين مختلف العوامل الاقتصادية والمؤسسية (الحوكمة). وتشمل المتغيرات الرئيسية في نموذج الدراسة، انبعاثات ثاني أكسيد الكربون للفرد، والناتج المحلي الإجمالي الحقيقي للفرد، وفعالية الحكومة، والتطور المالي، والاستقرار السياسي واستهلاك الطاقة المتجددة، واستخدام الطاقة، والنسبة المئوية لسكان الحضر من جملة السكان. واعتمدت منهجية الدراسة على النموذج القياسي المبني على حزم البيانات المقطعية الزمنية (Panel Data) والممتدة من عام 1996 إلى عام 2022، وقد تم استخدام منهجية التكامل المشترك (CCR)ونموذج تصحيح الخطأ (VEC) لدراسة العلاقات طويلة المدى بين هذه المتغيرات. ولقياس أثر حجم التكامل في المدي الطويل فقد تم استخدام نموذجي المربعات الصغرى الديناميكية (DOLS) والمعدلة (FMOL). وتستند النتائج إلى مجموعة بيانات مكونة من 13 دولة عربية، تم اختيارها بناءً على توفر البيانات. وكشفت الإحصاءات الوصفية عن تباين كبير في انبعاثات ثاني أكسيد الكربون والمتغيرات الرئيسية الأخرى، مما يشير إلى الحاجة إلى تحليل شامل. كما أظهرت نتائج اختبارات التكامل المشترك الي وجود تكامل مشترك كبير بين المتغيرات، مما يشير إلى وجود علاقة طويلة الأمد بينهما. كما أتي معدل تصحيح الخطأ (ECT) سالباً، حيث يُعبر معامل تصحيح الخطأ (ECT) السالب عن ضرورة تصحيحه سنويًا. هذه المعامل السلبي يشير إلى عملية تعديل مستقرة. وبناءً على النتائج أعلاه، تقدم هذه الدراسة رؤى قيمة في العلاقات المعقدة بين العوامل الاقتصادية، والحوكمة، واستهلاك الطاقة، والتحضر، وانبعاثات ثاني أكسيد الكربون في الدول العربية. يمكن أن تساعد تنفيذ السياسات الموصي بها هذه الدول في تحقيق تقدم في جهود خفض الكربون، مع ضمان النمو الاقتصادي المستدام وحماية البيئة.

* **Associate Professor in Economics. Sultan Qaboos University. Email: sufian@squ.edu.om**

1. Introduction

Arab oil exporters have endured the challenges of the oil crisis in the 1980s, the significant price drop in 2014, and the OECD countries' shift towards greater decarbonization of economic activities. Despite these challenges, climate change and the energy transition have become critical issues on the agenda (Beck & Richter, 2022). Economically, export revenues are projected to decline due to developments in the global economy, making it clear that future growth models cannot depend on the steady flows of hydrocarbon revenues that have characterized the past. This situation is further complicated by these countries' lack of preparedness for the economic disruptions caused by climate change. In addition to the decline in important tax revenues, the costs associated with extreme weather events will continue to fluctuate. Addressing climate change and its consequences will undoubtedly impose some costs on economic growth, but the costs of inaction could be far greater (Hereher & El Kenawy, 2020) (Alnaser and Alnaser, 2020) (Praveen et al.2020).

Addressing the pressing issue of climate change is a paramount global concern. The repercussions, including escalating temperatures, water scarcity, and extreme weather events, are already putting significant pressure on ecosystems and human populations. Excessive hydrocarbon consumption is the primary driver of greenhouse gas (GHG) emissions, which are the main contributors to global warming. The global energy demand landscape is dominated by fossil fuels, necessitating a transition to a low-carbon mode of production. This shift towards clean energy is essential for decarbonizing the economy and mitigating the adverse effects of climate change by reducing carbon emissions. Additionally, it supports economic development by preventing energy poverty and enhancing access to electricity, (IPCC (2014) Climate Change 2014).

Countries in the Middle East and North Africa (MENA) region are actively seeking ways to transform their energy systems into low-carbon models. Many Arab nations, having signed the Paris Agreement in 2016, have committed to combating climate change. Consequently, these countries have set ambitious objectives and formulated plans to increase renewable energy production while reducing GHG emissions.

The Arab region has historically been recognized for its vast reserves of oil and natural gas, which have significantly contributed to its economic growth and development. Possessing approximately half of the world's known oil and gas reserves, the region remains a cornerstone of the global hydrocarbons supply. In

2017, it accounted for 37% of the world's oil production and 22% of global gas production (Simone Tagliapietra (2019). Saudi Arabia is the dominant oil producer in the region, with Iraq, the United Arab Emirates, and Kuwait following. In terms of natural gas production, Qatar leads, followed by Saudi Arabia, Algeria, and the United Arab Emirates (Figures 1 & 2).

However, overreliance on fossil fuels has not only contributed to global carbon emissions but also exposed these nations to economic volatility due to oil price fluctuations. In recent years, Arab countries have recognized the imperative of transitioning to cleaner and more sustainable energy sources to address environmental concerns, enhance energy security, and foster economic diversification, Saidi H, El Montasser G, Ajmi AN (2020).

The Arab region's significance in the global energy landscape cannot be overstated. It harbors some of the world's largest oil and natural gas reserves, serving as a cornerstone of the global energy supply chain for decades. This reliance on hydrocarbons has been a double-edged sword, providing economic prosperity while significantly contributing to carbon emissions. Consequently, Arab countries are currently grappling with the urgent challenge of diversifying their energy portfolio, reducing their carbon footprint, and embracing sustainable energy solutions.

The objective of this paper is to propose hypotheses regarding the trends and prospects for decarbonization and the transition away from hydrocarbons in the Arab region. Climate change will disproportionately impact developing countries, including Arab nations, due to their socio-economic conditions and geographical locations. Higher temperatures, reduced agricultural productivity, and increasing water scarcity are expected to have severe impacts. Additionally, measures to combat climate change could bring energy security issues, as these countries rely heavily on exporting oil and fossil fuel consumption, making them particularly vulnerable to the physical impacts of climate change.

The study is structured as follows: Section one provides an introduction. The second section presents the Initiatives for Energy Transition in Arab Countries. This is followed by the third section, which discusses the Challenges and Barriers to Energy Transition in Arab Countries. The fourth section highlights the Literature Review. The fifth section is dedicated to model specification and data. Section six focuses on the Empirical Findings. Finally, the seventh section provides the conclusion of the study and offers a set of recommendations.

1.1 Motivation and Rationale

Climate change action has become a significant concern for fossil fuel-producing nations as they navigate the global shift towards decarbonizing economies. The burning of fossil fuels is a primary driver of climate change, necessitating cleaner and more efficient energy use to mitigate global warming, (Perera & Nadeau, 2022) (Kabir et al.2023). This study investigates the implications of decarbonization for Arab oil-producing countries, focusing on its impact on national development strategies, inclusive development, and social welfare. It also examines energy transition, its alignment with international commitments, sustainable development pillars, and the guiding principles and policies for economic diversification and job creation in the region.

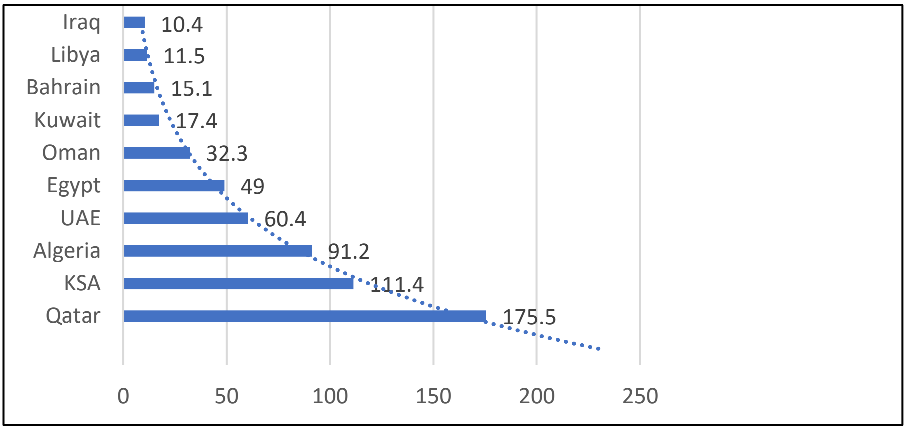
In the 21st century, sustainability is paramount due to the challenges posed by climate change and resource depletion. The Arab region, known for its oil reserves and energy-centric economies, faces a critical juncture. This study aims to understand and assess decarbonization and sustainable energy transition dynamics in Arab nations. These countries play a crucial role in the global energy landscape, and their decisions will impact global sustainability, energy security, and climate change mitigation.

1.2 Research Problem

Arab countries face several challenges in managing climate change mitigation, decarbonization, and the transition to clean energy sources. These challenges include economic dependency on fossil fuels, social and political inertia, and the need for substantial investments in new technologies and infrastructure. The transition to sustainable energy is further complicated by regional conflicts, varying levels of development, and differing national priorities.

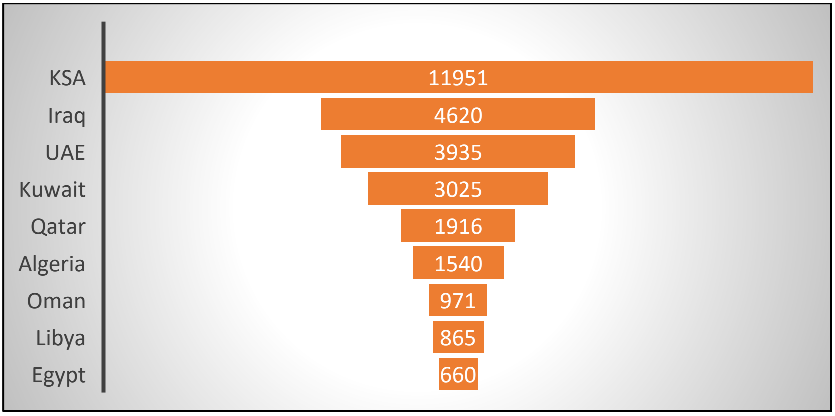
Given these complexities, there is a critical need for a comprehensive and nuanced understanding of the opportunities and problems associated with climate change, decarbonization initiatives, and the transition to sustainable energy sources in Arab nations.

Figure (1): Natural gas (billion cubic meters per year)



Source: Authors own creation based on data adapted from: (BP, S. (2002). BP Statistical review of world energy 2002. *http://www. bp. com/*.)

Figure (2): Oil (thousand barrels per day)



Source: Authors own creation based on data adapted from:((BP, S. (2002). BP Statistical review of world energy 2002. *http://www. bp. com/*.)

The next section will delve into the specific initiatives undertaken by Arab countries to transition towards cleaner and more sustainable energy sources. This includes examining the strategies, policies, and projects that are driving the shift from fossil fuels to renewable energy within the region.

2. Initiatives for Energy Transition in Arab Countries

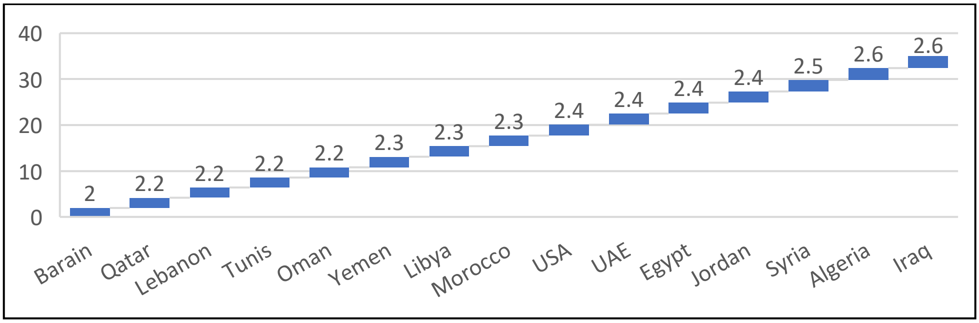
The global shift towards decarbonization, highlighted by projections from the International Energy Agency (IEA) and OPEC, offers both challenges and opportunities for the Middle East. To meet the net-zero target by 2050, the IEA advocates for ceasing investments in fossil fuels and reallocating capital towards reducing carbon emissions (IEA, 2021).

Energy investment and the transition to sustainable energy sources are critical for the future of our planet. Climate change is a well-recognized and documented issue. In September 2016, the Paris Agreement was signed by 115 countries at the United Nations headquarters in New York (Tørstad, 2020; Guzović et al., 2023). This agreement included commitments from each signatory, known as Intended Nationally Determined Contributions (INDCs). Article 2 of the Paris Agreement outlines specific goals for mitigation, adaptation, and financial support. The primary aim of the Agreement is to limit the increase in global average temperature to well below 2 degrees Celsius above pre-industrial levels, with efforts to cap the rise at 1.5 degrees. Following the COP24 final decision, all participating countries are required to communicate their strategies and targets via the Enhanced Transparency Framework and to update their INDCs by 2020 (UNFCCC, 2018).

The 2015 Paris Climate Agreement, aiming to limit the global temperature rise to 1.5° C by 2030 presents a significant challenge for Arab countries, which are heavily dependent on fossil fuels. Although climate change has a profound impact on the region, these concerns have often been neglected by Arab governments in their energy and fiscal policy decisions (Höhne et al., 2021; Huang & Zhai, 2021; Meinshausen et al., 2022).

According to projections (See figure 3 below), the Arab region will experience a temperature increase of approximately 2 degrees Celsius between 2039 and 2040, with peak summer temperatures rising by around 2.5 degrees Celsius. Furthermore, it is estimated that by 2050, temperatures in the Arab world could rise by up to 4 degrees Celsius. This alarming trend underscores the urgency for Arab countries to address climate change proactively.

Figure (3): Projected Temperature in Arab Counties (2040-2059)



Source: Authors own creation (Based on: IMF Climate Change Indicator Dashboard), https://climatedata.imf.org/

2.1 National Renewable Energy Targets

Countries in the Middle East are increasingly setting ambitious renewable energy targets as part of their efforts to transition to sustainable energy sources. Saudi Arabia is actively pursuing renewable energy deployment within a restructured energy policy framework, motivated by rapidly rising domestic energy demand. Despite its substantial solar and wind energy resources, these remain relatively under-exploited. In 2012, Saudi Arabia announced a new energy policy with ambitious renewable energy targets, aiming to install 41 GW of solar power, which would constitute around a third of the country's peak load, and 16 GW of wind power by 2040 (Ali, 2023; Belaïd & Al-Sarihi, 2024; Magrassi et al. 2019). The deployment's timing, location, and investment planning for grid capacity were still under consideration. The development of the King Abdullah City for Atomic and Renewable Energy marks the initial step towards implementing these national renewable energy plans. The objectives include integrating renewable energy systems, coordinating related research programs, collaborating with public and private sectors for investment and project development, and encouraging local involvement (Alruwaished et al., 2023; Suliman, 2024; Di Lorenzo et al., 2024).

Additionally, other countries in the region, such as Morocco and Jordan, have established specific national targets for the share of renewable energy in their energy mix. Morocco aims for 14% renewable energy by 2020 and 42% by 2030, while Jordan's target is 10% by 2020. Jordan also has long-term goals for solar photovoltaics and solar thermal power, aiming for these to produce 30% and 25%

of the country's electricity, respectively, by 2030 (Azzuni et al., 2020; Kiwan & Al-Gharibeh, 2020; Dadashi et al., 2022; Abu-Rumman et al., 2020).

2.2. Investment in Renewable Energy Projects

Investment in renewable energy projects across various MENA countries showcases significant financial commitments and strategic initiatives aimed at advancing sustainable energy infrastructure. Tunisia has allocated approximately $30 million USD annually towards subsidized measures supporting renewable energy projects (Kiyasseh, 2024). Morocco has secured substantial international financing, including a $299 million USD investment from the IFC “International Finance Corporation”(1) facilitating the development of MW-scale CSP (2)projects (Kiyasseh, 2024; Dissou, 2020). Algeria has implemented feed-in tariffs, tax incentives, and a $64 billion USD development program, with a substantial portion dedicated to renewable technologies (Kiyasseh, 2024; Dissou, 2020). Egypt's Renewable Energy and Energy Efficiency Program (REEEP) includes a $1 billion USD initiative supported by the World Bank, focusing on scaling up renewable energy and enhancing energy efficiency (Zahraoui et al., 2021; Bouraiou et al., 2020).

Moving forward, the UAE has launched the Masdar renewable energy company with a planned investment ceiling of approximately $200 billion USD, demonstrating its commitment to sustainable energy development (Zumbraegel, 2022; Yoncacı, 2023). Bahrain aims to invest $10 billion USD over four years in renewable energy initiatives (Zumbraegel, 2022; Yoncacı, 2023). Saudi Arabia has earmarked $109 billion USD to install up to 41 GW of solar PV(3), concentrated solar power, and wind energy capacities by 2032 (Kiyasseh, 2024; Dissou, 2020). Jordan has implemented a feed-in tariff scheme with an investment of $600 million USD to promote renewable energy resources (Khalil, 2021; Amran et al., 2020). These efforts underscore a regional push towards sustainable development and

(1) **IFC “International Finance Corporation”**: The International Finance Corporation (IFC) is a member of the World Bank Group. It focuses on private sector development in developing countries, providing investment, advice, and asset management services to encourage private sector growth and reduce poverty. For detailed information check, https://www.ifc.org/en/about

(2) **CSP projects**: Concentrated Solar Power (CSP) projects use mirrors or lenses to concentrate sunlight onto a small area to produce heat. This heat is then used to generate electricity through traditional steam turbines or engines that drive a generator. For Morocco ‘s Project Profiles, Check, https://solarpaces.nrel.gov/by-country/MA

(3) **Solar PV**: Solar Photovoltaic (PV) technology converts sunlight directly into electricity using solar cells made of semiconductor materials. Solar PV systems can be used for a variety of applications, from small-scale residential rooftops to large-scale solar farms.

energy diversification, bolstered by substantial financial commitments and international partnerships.

2.3. Hydrogen Economy

MENA ranks among the cheapest hydrogen production locations in the world; with expected hydrogen production prices of <$1.50/kgH2 in 2030−2035. Some countries are exploring hydrogen as a clean energy source. Saudi Arabia, for instance, aims to become a global leader in green hydrogen production. The country has initiated projects to produce green hydrogen using renewable energy sources and plans to export it to international markets. Current estimated storage capacity is 170Gt of CO_2, which is the highest in the world

2.4. Carbon Capture and Storage (CCS)

Current estimated storage capacity is 170Gt of CO_2, which is the highest in the world. Some Arab countries are investing in carbon capture and storage technologies to reduce emissions from their existing fossil fuel infrastructure. For example, the UAE's Al Reyadah CCS project captures CO_2 emissions from an industrial plant and stores it underground.

2.5. Energy Efficiency

Improving energy efficiency is a priority for many Arab nations. Countries like Qatar and the UAE have introduced energy efficiency programs to reduce energy consumption in various sectors, including industry, transportation, and buildings

Although Arab countries have made notable progress towards energy transition, significant challenges and barriers persist, as summarized in the following section.

3. Challenges and Barriers to Energy Transition in Arab Countries

The energy transition in Arab countries faces several significant challenges and barriers. Firstly, despite rich renewable energy potential, the traditional dominance of fossil fuels poses inertia towards diversification (See Table 1). Secondly, varying levels of institutional capacity and regulatory frameworks across different nations complicate unified progress. Thirdly, financial constraints and economic dependencies on hydrocarbon revenues create fiscal challenges in funding sustainable energy projects. Lastly, geopolitical tensions and regional instability can disrupt long-term planning and investment in renewable infrastructure, necessitating robust strategies for resilience and adaptation in energy transition efforts.

Table (1): Comparison of Installed Renewable Energy Capacity vs. National Targets (2022) in Selected Arab Countries

Country	Share of renewable energy in total electricity capacity	National renewable energy targets
Hydrocarbon exporting GCC economies		
Bahrain	0.10%	5% by 2025 and 10% by 2035 of electricity generation
Kuwait	0.40%	15% by 2030 of electricity generation
Qatar	0.10%	200-500 MW of solar by 2020
Oman	0.40%	10% by 2025 and 30% by 2030 of electricity generation
Saudi Arabia	0.20%	3.45 GW by 2020; 9.56 GW by 2023 (10% of cap), and 30% of electricity generation from renewables, nuclear, and others
UAE	7.00%	Abu Dhabi 7% of capacity by 2020; Dubai 7% of electricity generation by 2020; Ras al-Khaimah 20-30% clean energy by 2040; total UAE 27% clean energy by 2021, 44% of capacity by 2050
Select hydrocarbon importing Arab economies		
Egypt	20%	42% by 2035 of electricity generation
Jordan	21%	35% by 2035 of electricity generation
Morocco	34%	42% by 2020 and 52% by 2050 of installed capacity
Tunisia	8%	30% by 2035 of installed capacity

Source: Update from Table 1 in Shehabi, M. “The Hurdles of Energy Transitions in Arab States,” in Frederic Wehrey (ed.), “Disruptions and Dynamism in the Arab World,” Carnegie Endowment for International Peace, May 3, 2023, The data presented in Table 1 highlights the disparity between the current installed renewable energy capacity and the ambitious national targets set by various Arab countries. The analysis can be segmented into two groups: hydrocarbon-exporting GCC economies and hydrocarbon-importing Arab economies.

3.1 Hydrocarbon Exporting GCC Economies

Bahrain faces a significant challenge in achieving its renewable energy targets, with only 0.10% of its electricity capacity currently derived from renewables. The country aims to increase this to 5% by 2025 and 10% by 2035, necessitating substantial efforts and investments to meet these ambitious goals. Similarly, Kuwait's renewable energy capacity stands at a mere 0.40%, far from its target of 15% by 2030. This indicates a substantial gap that the country needs to bridge through accelerated adoption and development of renewable energy technologies.

Qatar, with only 0.10% of its energy capacity from renewables, also struggles to meet its renewable energy targets. The country's goal of achieving 200-500 MW of solar capacity by 2020 appears unmet, signaling an urgent need for increased efforts and investment in renewable energy.

Oman's renewable energy capacity is currently at 0.40%, similar to Bahrain and Kuwait. This is significantly below its targets of 10% by 2025 and 30% by 2030, underscoring the necessity for a more aggressive approach to renewable energy adoption and infrastructure development.

Saudi Arabia, with just 0.20% of its energy capacity from renewables, faces a considerable challenge in scaling up its renewable energy infrastructure. The country had set targets of 3.45 GW by 2020 and 9.56 GW by 2023, but the current figures highlight a significant shortfall that must be addressed through substantial expansion efforts. In contrast, the UAE shows a relatively higher renewable energy share at 7.00%, indicating more substantial progress compared to its regional counterparts. However, the UAE's ambitious target of reaching 44% renewable energy capacity by 2050 will still require significant expansion and continued commitment to renewable energy development.

3.2 Hydrocarbon Importing Arab Economies

Egypt has made substantial progress in its renewable energy journey, with 20% of its electricity capacity currently derived from renewables. This significant advancement indicates that the country is on a promising path towards achieving its ambitious target of 42% by 2035, showcasing the effectiveness of its renewable energy strategy.

Jordan, with 21% of its electricity capacity from renewables, is well-positioned to meet its goal of 35% by 2035. This progress reflects the country's commitment to expanding its renewable energy sector and the success of its policies and initiatives aimed at increasing renewable energy adoption.

Morocco stands out in the region with a remarkable 34% share of its electricity capacity coming from renewable sources. This achievement brings Morocco close to its target of 42% by 2020, demonstrating a strong commitment and effective implementation of renewable energy projects.

Tunisia, on the other hand, currently derives 8% of its electricity capacity from renewables, indicating that it still has a considerable distance to cover to meet its 30% target by 2035. Achieving this goal will require significant policy enhancements and infrastructural advancements to accelerate the adoption of renewable energy sources.

The hydrocarbon-exporting countries generally lag behind in renewable energy capacity compared to their ambitious targets, reflecting the challenges in transitioning from a hydrocarbon-based energy system. This could be due to several factors, including economic reliance on hydrocarbons, policy implementation delays, and infrastructural constraints.

On the other hand, hydrocarbon-importing countries like Egypt, Jordan, and Morocco have made more significant strides, possibly driven by the need to reduce energy import costs and enhance energy security. Their progress suggests more robust policy frameworks and greater investment in renewable energy infrastructure.

The next section offers a comprehensive analysis of existing research pertinent to the study. It synthesizes key findings, identifies gaps, and situates the current research within the wider academic context.

4. Literature Review

Arab countries are particularly vulnerable to the impact of climate change due to their arid climates, scarce water resources, and high temperatures. Climate change exacerbates existing environmental stresses, leading to severe consequences for water security, agriculture, and human health (Verner et al., 2018). The Intergovernmental Panel on Climate Change (IPCC) emphasizes the urgent need for these nations to adopt adaptive and mitigative strategies (IPCC, 2021).

Research on climate change, decarbonization, and energy transition in Arab countries provides crucial insights. Studies underscore the significance of energy efficiency (EE), economic development, urbanization, fossil fuel (FF) usage, and renewable energies (RE) in mitigating carbon dioxide emissions (CO2) in the Middle East and North Africa region (MENA) (Saeid et al., 2023; Jessie & Moritz, 2022). The Arabian Peninsula, heavily reliant on fossil fuels, faces challenges in transitioning to cleaner energy sources amidst global decarbonization efforts (Jessie & Moritz, 2022). Countries like Indonesia and the European Union (EU) are committed to reducing emissions through energy transitions and increasing renewable energy shares, with the EU leading in net-zero emissions commitments by 2050 (Ariana et al., 2023).

Decarbonization, achieved through adopting low-carbon technologies and practices, is critical for mitigating climate change in Arab countries. Various decarbonization strategies are being initiated, primarily driven by international commitments such as the Paris Agreement. For example, Saudi Arabia's Vision 2030 and the UAE's Energy Strategy 2050 outline ambitious plans to reduce carbon emissions and increase the share of renewable energy in their energy mix (Kingdom of Saudi Arabia, 2016; UAE Government, 2017).

The energy transition from fossil fuels to renewable energy sources, particularly solar and wind power, is pivotal for achieving sustainable development and mitigating climate change in Arab countries. Research indicates that investments in renewable energy can enhance energy security, reduce greenhouse gas emissions, and create economic opportunities (Al-Mulali et al., 2013).

Several studies employing panel cointegration approaches have explored the nexus between energy consumption, economic growth, and carbon emissions in Arab countries. For instance, Al-Mulali and Ozturk (2016) found evidence of cointegration and causality among energy consumption, CO2 emissions, and economic growth in the MENA region. Similarly, Salahuddin et al. (2018) highlighted the positive role of renewable energy consumption in reducing emissions and promoting economic growth in the GCC countries.

Studies also examine the Environmental Kuznets Curve hypothesis in the context of Arab nations, Awad & Abugamos (2017) identified an inverted-U pattern between income and CO2 emissions, supporting the EKC hypothesis within the

Arab context. However, variations in income disparities among these nations were noted as a limitation.

Comparative analyses, such as that by Andriamahery & Qamruzzaman (2022), highlight the interconnectedness of renewable energy adoption, energy innovation, and trade openness with environmental sustainability in Tunisia and Morocco.

Building upon the foundations laid by Apergis, N. and Payne, J.E. (2009), as well as Payne, J. (2010), Arouri, M.E.H., Youssef, A.B., and M'henni, H. (2012) conducted an analytical study using bootstrap panel unit root tests and cointegration approaches. Their research aimed to explore the complex relationships between CO2 emissions, economic complexity (EC), and economic growth rate (EGR) across 12 Arab nations from 1981 to 2005. Their findings revealed a lasting influence of economic complexity on CO2 emissions over the long term, while the evidence supporting the Environmental Kuznets Curve (EKC) hypothesis appeared relatively weak.

In another study, Al-Rawashdeh, Jaradat, and Al-Shboul (2014) scrutinized time series data from 1960 to 2010 to examine the association between economic growth rate (EGR) and CO2 emissions within the Arab region. Their rigorous analysis did not find conclusive evidence supporting the EKC for Arab nations as a whole. However, they identified the EKC phenomenon at the country level in Algeria, Tunisia, Yemen, Morocco, Turkey, and Libya.

The relationship between financial development, foreign direct investment (FDI), energy transition, and climate change in Arab countries has been extensively studied. Research indicates that financial development plays a crucial role in attracting FDI for energy transition and decarbonization efforts Ahlam, El, Fakiri., Kenza, Cherkaoui. (2022). [Saeid, Satari, et al., (2023). Shuwen, Ju., eat al., (2023). Studies emphasize the importance of transitioning from fossil fuels to renewable energies to mitigate climate change impacts, with renewable energies contributing to reducing CO2 emissions in the long run Hichem, Saidi., Ghassen, El, Montasser., Nadia, Doytch. (2022). Furthermore, the presence of bidirectional causality between FDI and financial development in Gulf Cooperation Countries highlights the potential for financial systems to facilitate investments in renewable energy sources, aiding in the shift towards environmentally friendly resources for electricity generation Rozina, Shaheen. (2023). These insights underscore the significance of financial mechanisms in driving sustainable development and combating climate change in the Arab region.

5. Model Specification and Data

The aim of this study is to explore the evolving connection between decarbonization, economic growth, and pertinent factors within 12 Arab countries (Algeria, Egypt, Lebanon, Syria, Sudan, Saudi Arabia, Tunisia, Morocco, Iraq, the United Arab Emirates, Jordan, and Libya), selected for their robust data availability and comprehensive coverage, over the period, 1996 to 2022.

The following models are used to examine this interconnected relationship:

$$\text{Ln } \mathbf{CO_2} = \alpha_0 + \alpha_1 \text{Ln } GDPPC_{it} + \alpha_2 \text{Ln } ENGU_{it} + \alpha_3 \text{ Ln } URPN_{it} + \alpha_4 \text{ } GVEF_{it} + \alpha_5 \text{ } FDEV_{it} + \alpha_6 \text{Ln } RENEN_{it} + \alpha_7 \text{LnPOLS } \varepsilon_{it}$$

In the given model, we have specified a multiple regression equation with Ln CO_2 (natural logarithm of carbon dioxide emissions) as the dependent variable. Let's delve into the independent variables and discuss their likely effects on Ln CO_2, whether they are positive or negative.

1. Ln $GDPPC_{it}$ (Per Capita GDP): The coefficient α 1 represents the effect of per capita GDP on carbon emissions. Typically, as a country's per capita GDP increases, it indicates higher economic development. In this context, a positive relationship is often observed, meaning that as the economy grows, carbon emissions tend to increase due to increased industrialization, energy consumption, and transportation. Therefore, α_1 is likely to be positive, $\alpha_1 > 0$
2. $ENGU_{it}$ (Energy Use): The coefficient α_2 represents the effect of energy use per capita on carbon emissions. Higher energy use is generally associated with higher carbon emissions, as most energy sources involve the combustion of fossil fuels. Hence, α_2 is also likely to be positive. $\alpha_2 > 0$
3. $URPN_{it}$ (Urban Population Percentage): The coefficient α_3 signifies the impact of the percentage of urban population on carbon emissions. Urbanization often leads to increased energy consumption and emissions due to factors like increased transportation and energy demand. Thus, α_3 is likely to be positive. $\alpha_3 > 0$.
4. $GVEF_{it}$ (Government Effectiveness): Effective governance can lead to better environmental regulations, which may reduce emissions (negative effect). However, if government is not effective, it could also increase emissions (positive effect). The direction of α_4 will depend on how

government effectiveness impacts the economy and environmental policies. ($\alpha_4 < 0$ or $\alpha_4 > 0$)

5. $FDEV_{it}$ (Financial Development Variable): A developed financial sector can promote green investments and sustainable practices, potentially reducing emissions (negative effect). Conversely, if financial development leads to increased industrial activity, it might raise emissions (positive effect). Like other variables, the direction of α_5 will depend on specific circumstances. ($\alpha_5 < 0$ or $\alpha_5 > 0$). Here is proxied by domestic credit to private sector as a percentage of GDP.
6. Ln $RENEN_{it}$ represents the natural logarithm of renewable energy consumption (% of total final energy consumption) at year t. Increased consumption of renewable energy is generally associated with lower carbon emissions as it replaces fossil fuel-based energy sources. Therefore, the coefficient α_6 is expected to be negative ($\alpha_6 < 0$).
7. Ln POLS: The natural logarithm of political stability is generally expected to have a negative relationship with CO_2 emissions per capita ($\alpha_7 < 0$).
8. ε_{it} (Error Term): The error term ε it captures unexplained variation in carbon emissions that is not accounted for by the independent variables in the model. It encompasses other factors and random variability.

The following table provides a detailed description of the variables used in the study and their respective data sources.

Table (2): Variables' description and data sources

Variable	Definition	Codes	Source
Dependent variable	CO_2 emissions (metric tons per capita	CO_2	WDI, 2022
	Real GDP at constant 2011 national prices (Converted to the equivelant USD million, 2011)	$GDPPC_{it}$	PWT 10.0
	Energy use (kg of oil equivalent per capita	$UNGU_{it}$	WDI, 2022

Variable	Definition	Codes	Source
Independent variables	Government Effectiveness	$GVEF_{it}$	WDI, 2022
	Urban Population	$URPN_{it}$	WDI, 2022
	Renewable energy consumption	$RENEN_{it}$	WDI, 2022
	Political Stability	$POLS_{it}$	WDI, 2022
	Financial Development Index	$FDEX_{it}$	WDI, 2022

Source: World Bank "World Development Indicators" and Penn world Table 10.0

6. Empirical Findings

6.1 Descriptive Analysis

Table (3): Summary Statistics for the Model Variables

Series	Ln CO_2	Ln FDEV	Ln ENUS	Ln GDPPC	Ln GVEF	Ln POLS	Ln RENEN	Ln URPN
Mean	5.76	42.28	2163.71	8995.27	-0.43	-0.8	10.14	61.50
Median	2.94	36.20	963.56	3978.92	-0.36	-0.56	2.84	68.49
Maximum	30.93	121.71	12172.41	62264.91	2.32	4.109	83.61	91.84
Minimum	0.174	1.267	-37.78	952.15	-2.14	-3.14	0.01	2.32
Std. Dev.	6.60	29.51	2636.29	12628.66	0.78	1.12	18.86	24.81
Skewness	1.960	0.39	1.9437	2.63	0.24	0.16	2.71	-0.99
Jarque-Bera	340.48	19.93	306.73	929.6	3.168	5.49	892.22	51.82
Sum	1821.4	13363.0	683734.0	2842505.	-137.43	-253.16	3206.44	19434.3
Sum Sq. Dev.	13734.	274242.	2.19E+09	5.02E+10	194.45	397.911	112097.7	193845.5
Observations	316	316	316	316	316	316	316	316

Source: Calculated using E-Views 12 software.

Table 3 displays a broad spectrum of values across economic, environmental, and governance metrics, showcasing significant diversity among the observed indicators. Key variables like CO_2 emissions, financial development

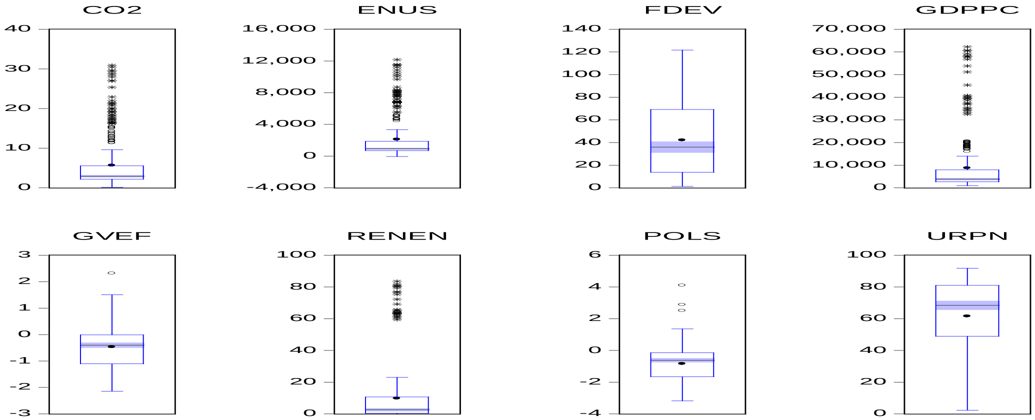
(FDEV), and GDP per capita (GDPPC) exhibit considerable disparities between their minimum and maximum values, highlighting varying socio-economic conditions across studied regions. High standard deviations further underscore the heterogeneous nature of these factors within the dataset, emphasizing the complex interplay of influences on economic development, environmental sustainability, and governance effectiveness. Specifically, variables such as Energy Use per capita (ENUS), GDP per capita (GDPPC), and Urban Population Percentage (URPN) demonstrate substantial variability, reflecting diverse patterns in energy consumption, economic prosperity, and urbanization rates among the analyzed units.

6.2 Check for Outliers, Multicollinearity and Endogeneity

6.2.1. Outliers

The box plots in Figure 4 display distinct patterns for various variables across Arab countries. CO2 emissions and energy use exhibit right-skewed distributions with outliers, indicating that while most countries have low values, a few have significantly higher levels. Financial development has a symmetric distribution with fewer outliers, showing variation in financial sector maturity. Per capita GDP and urban population percentage are also right-skewed with notable outliers, highlighting economic disparities. Government effectiveness and political stability have more symmetric distributions with some outliers, reflecting varied governance and stability. Renewable energy consumption is low in most countries but significantly higher in a few. The presence of skewness and outliers necessitates robust estimation techniques in the econometric analysis to account for these extreme values. Overall, the box plots illustrate the variability and distribution of key variables, which is crucial for understanding the dynamics in the study of climate change, decarbonization, financial development, FDI, and energy transition.

Figure (4): The box plots for Model variables



Source: Source: Calculated using E-Views 12 software.

6.2.2. Multicollinearity

Table 4 indicates that there is no significant multicollinearity among the key variables, as assessed by the Variance Inflation Factor (VIF) with a threshold typically set at 10. VIF values for all variables are well below this threshold, ranging mostly between 1 and 2. This suggests that the variables in the model are largely independent of each other, supporting the reliability of regression coefficient estimates and indicating that each variable contributes unique explanatory power to the model.

Table (4): Variance Inflationary Vector (VIF)

Variable	VIF	1/VIF
Ln CO_2	1.67	0.59
Ln ENUS	1.52	0.66
Ln POLS	1.18	0.84
Ln GDPPC	1.32	0.76
Ln FDEX	1.71	0.58
Ln GVEF	1.02	0.98
Ln RENEN	1.19	0.84
Ln URPN	1.78	0.56

Source: Authors own Calculation

6.2.3. Endogeneity

The Two-Stage Least Squares (2SLS) method is widely utilized in econometric modeling to address endogeneity issues. Endogeneity occurs when an explanatory variable is correlated with the error term, which can bias Ordinary Least Squares (OLS) estimates. 2SLS resolves this by using instrumental variables (IVs) that correlate with the endogenous variables but are independent of the error term, ensuring consistent coefficient estimation.

Table 5 presents the outcomes of the 2SLS regression applied in this study to mitigate endogeneity. It reports coefficients, standard errors, t-statistics, and p-values for independent variables (GVEF, POLS, GDPPC, FDEV, ENUS, URPN). The high F-statistic (5938.68) indicates robust statistical significance and a strong model fit. These results underscore significant relationships between these variables and CO2 emissions, reinforcing the reliability of our findings.

Table (5): Two-Stage Least Squares Results

Dependent Variable: CO_2
Method: Two-Stage Least Squares
Sample: 1 326
Instrument specification: RENEN GVEF POLS GDPPC FDEV ENUS URPN
Constant added to instrument list

Variable	Coefficient	Std. Error	t-Statistic	Prob.
GVEF	-0.455483	0.087668	-5.195517	0.0000
POLS	0.074228	0.045270	1.639666	0.1021
GDPPC	0.024843	0.001921	12.92964	0.0000
FDEV	0.008217	0.001921	4.276819	0.0000
ENUS	0.001829	4.82E-05	37.91862	0.0000
URPN	0.000136	9.78E-06	13.85860	0.0000
C	0.265785	0.120447	2.206665	0.0281
R-squared	0.992645	Mean dependent var		5.763947
Adjusted R-squared	0.992478	S.D. dependent var		6.603159
S.E. of regression	0.572678	Akaike info criterion		1.748003
Sum squared resid	101.0116	Schwarz criterion		1.843085
F-statistic	5938.676	Hannan-Quinn criterion		1.785988

Source: Calculated using E Views 12 software.

6.3 Panel Unit Root Test

The panel root test results in Table 6 indicate that most variables (Ln CO2, Ln ENUS, Ln POLS, Ln GDPPC, Ln FDEX, Ln RENEN, and Ln URPN) are non-stationary at their levels but become stationary after taking the first difference, as evidenced by the p-values being above 0.05 at the level and below 0.05 at the first difference across various tests (Levin, Lin & Chu t, Im, Pesaran and Shin W-stat, ADF - Fisher Chi-square, and PP - Fisher Chi-square). Specifically, for Ln CO_2, Ln ENUS, Ln POLS, Ln GDPPC, Ln FDEX, and Ln RENEN, all tests confirm stationarity after differencing, indicating they are integrated of order one, I(1). Ln GVEF shows mixed results at the level but is consistently stationary after differencing. Therefore, these variables require differencing to achieve stationarity before further analysis.

These findings underscore the importance of first differencing to achieve stationarity for most variables, ensuring reliable and robust econometric analysis in the study of dynamic relationships among these variables.

Table (6): Panel Root Test

Variables	**Levin, Lin & Chu t**		**Im, Pesaran and Shin W-stat**		**ADF - Fisher Chi-square**		**PP - Fisher Chi-square**	
	Level p-value	First Difference p-value	Level p-value	First Difference p-value	Level p-value	First Difference p-value	Level p-value	First Difference p-value
Ln CO_2	0.1287	0.0021	0.0452	0.0000	0.0564	0.0043	0.4567	0.0000
Ln ENUS	0.7658	0.0010	0.7635	0.0067	0.0566	0.0023	0.7632	0.0001
Ln POLS	0.3454	0.0022	0.6564	0.9843	0.9864	0.0065	0.3431	0.000
Ln GDPPC	0.5634	0.0032	0.8675	0.0076	0.0987	0.0000	0.3876	0.0076
Ln FDEX	0.2321	0.0023	0.4321	0.0043	0.0124	0.0000	0.2318	0.0000
Ln GVEF	0.0011	0.0020	0.5621	0.0032	0.0352	0.0034	0.4541	0.0011
Ln RENEN	0.6734	0.0000	0.3221	0.0000	0.5643	0.0000	0.7876	0.0123
Ln URPN	0.2223	0.0000	0.5642	0.0000	0.4532	0.0000	0.567	0.0000

Source: Calculated using E-Views 12 software.

6.3 Panel Cointegration results

In this section, the Canonical Cointegrating Regression (CCR) model is utilized to estimate long-term equilibrium relationships among variables integrated of order one, I(1). To ensure accurate results and mitigate serial correlation issues, lagged values (lag 1 and lag 2) of the dependent variable are included in the model. This adjustment aims to effectively capture autocorrelation patterns, enhancing the robustness of estimated coefficients and the reliability of long-term relationships between variables. CCR is renowned for its ability to address endogeneity and serial correlation, providing consistent and efficient estimates of these relationships. The results from CCR highlight significant impacts of several variables on CO_2 emissions (Table 7): ENUS (Energy Use) shows a positive and significant coefficient (0.000568, $p < 0.0215$), indicating higher energy use correlates with increased CO_2 emissions. Lagged values of CO_2 ($L1CO_2$ and $L2CO_2$) exhibit significant positive and negative relationships respectively. GVEF (Government Effectiveness) reveals a significant negative relationship (-0.359738, $p < 0.0317$) with CO_2 emissions, underscoring the role of effective environmental policies in emission reduction. While variables such as FDEV (Financial Development), POLS (Political Stability), URPN (Urbanization), RENEN (Renewable Energy), and GDPPC do not show statistically significant effects at conventional levels, they may still hold relevance in broader contexts. The high R-squared value (0.912) indicates that the model explains a substantial portion of CO_2 variation. To avoid the risk of error autocorrelation, and since some variables are cointegrated a vector error correction model will be used to estimate the equation.

Table (7): The result of Cointegrating Regression (CCR)

Dependent Variable: CO_2
Method: Canonical Cointegrating Regression (CCR)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
ENUS	0.000568	0.000246	2.311884	0.0215
FDEV	0.003177	0.003333	0.953181	0.3413
GDPPC	3.42E-05	2.19E-05	1.560209	0.1198
GVEF	-0.359738	0.166731	-2.157590	0.0317
L1CO2	1.382513	0.271846	5.085652	0.0000

Variable	Coefficient	Std. Error	t-Statistic	Prob.
L2C02	-0.676310	0.185630	-3.643322	0.0003
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
POLS	0.104280	0.079486	1.311924	0.1905
RENEN	-0.007658	0.004328	-1.769315	0.0779
URPN	0.000795	0.003356	0.236979	0.8128
C	-0.032315	0.203631	-0.158691	0.8740
R-squared	0.912053	Mean dependent var		5.803875
Adjusted R-squared	0.909432	S.D. dependent var		6.635927
S.E. of regression	1.997046	Sum squared resid		1204.434
Durbin-Watson stat	2.998790	Long-run variance		0.870116

Source: Calculated using E-Views 12 software.

6.4 The Vector Error Correction (VECM)

Before presenting results, it's essential to justify using the Vector Error Correction Model (VECM). VECM is a statistical model used to analyze non-stationary time series data that are cointegrated. It captures both long-term equilibrium relationships and short-term dynamics among the variables. VECM corrects deviations from long-term equilibrium, allowing for the study of how variables adjust over time to return to equilibrium, while also accounting for short-term fluctuations.

The Vector Error Correction Model (VECM) results reveal significant long-term relationships and short-term dynamics among the variables. In the cointegrating equation (CointEq1), ENUS shows a strong positive relationship with other variables, while FDEV, GDPPC, GVEF, POLS, and URPN also exhibit substantial impacts supported by their respective coefficients and high t-statistics. The error correction mechanism coefficients indicate how deviations from equilibrium are corrected over time, with negative coefficients suggesting a stable adjustment process (Table 8).

Table (8): Vector Error Correction Estimates

Cointegrating Eq:	CointEq1					
ENUS(-1)	1.000000					
FDEV(-1)	130.6571					
	(20.7111)					
	[6.30857]					
GDPPC(-1)	-0.063754					
	(0.03937)					
	[-1.61945]					
GVEF(-1)	-6734.398					
	(1060.91)					
	[-6.34778]					
POLS(-1)	2692.184					
	(514.977)					
	[5.22778]					
URPN(-1)	-77.43479					
	(18.6912)					
	[-4.14285]					
C	-3156.036					
Error Correction:	**D(ENUS)**	**D(FDEV)**	**D(GDPPC)**	**D(GVEF)**	**D(POLS)**	**D(URPN)**
CointEq1	-1.0165	-0.001281	0.136307	2.07E-05	-1.16E-05	-3.87E-05
	(0.4151)	(0.00027)	(0.09919)	(8.3E-06)	(1.2E-05)	(0.00012)
	[-2.449]	[-4.77768]	[1.37419]	[2.50619]	[-0.92846]	[-0.32419]

Source: Calculated using E-Views 12 software.

6.5. FMOLS and DOLS results

The motivation for using FMOLS and DOLS in panel data is to estimate the magnitude of long-run relationships between variables, enhancing the reliability and accuracy of the analysis. These methods provide unbiased and consistent estimates by correcting for endogeneity and handling serial correlation. They are particularly effective for cointegration analysis, capturing long-term equilibrium relationships among non-stationary variables.

The results presented in Tables 9 and 10 provide estimates of panel long-run elasticity using two different methods: Panel Fully Modified Least Squares (FMOLS) and Panel Dynamic Least Squares (DOLS). Both methods consistently show that energy use (ENUS), GDP per capita (GDPPC), government expenditure on environmental protection (GVEF), and renewable energy (RENEN) are significant determinants of CO2 emissions, with similar magnitudes and directions of coefficients. Financial development (FDEV) is insignificant in both models, similar to the findings of Siddique et al. (2016). Urbanization (URPN) is significant in the FMOLS results, aligning with the findings of Mohammed and Abdel-Gadir (2023).

Table (9): Results of FMOL

Dependent Variable: CO_2
Method: Fully Modified Least Squares (FMOLS)
Cointegrating equation deterministic: C

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Ln FDEV	0.001842	0.003305	0.557238	0.5778
Ln ENUS	0.001913	8.17E-05	23.42267	0.0000
Ln GDPPC	0.000122	1.66E-05	7.345817	0.0000
Ln GVEF	-0.634569	0.148195	-4.281990	0.0000
Ln POLS	0.134113	0.076748	1.747447	0.0816
Ln RENEN	-0.024791	0.003263	-7.596617	0.0000
Ln URPN	0.006554	0.003283	1.996754	0.0467
C	0.123592	0.204851	0.603326	0.5467
R-squared	0.992476	Mean dependent var		5.782751
Adjusted R-squared	0.992304	S.D. dependent var		6.619969
S.E. of regression	0.580736	Sum squared resid		103.1999

Source: Calculated using E-Views 12 software.

Table (10): Results of DOLS

Dependent Variable: CO_2
Method: Dynamic Least Squares (DOLS)
Cointegrating equation deterministic: C

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Ln FDEV	0.003299	0.003675	0.897674	0.3701
Ln ENUS	0.001947	8.09E-05	24.07962	0.0000
Ln GDPPC	0.000118	1.61E-05	7.342123	0.0000
Ln GVEF	-0.683323	0.180529	-3.785119	0.0002
Ln POLS	0.156828	0.087223	1.798003	0.0732
RENEN	-0.024318	0.003068	-7.926076	0.0000
URPN	0.005975	0.003165	1.887793	0.0601
C	0.061832	0.204141	0.302889	0.7622
R-squared	0.994753	Mean dependent var		5.780118
Adjusted R-squared	0.994230	S.D. dependent var		6.628436
S.E. of regression	0.503507	Sum squared resid		71.23892

Source: Calculated using E-Views 12 software.

6.6. Robust Check

The Robust Least Squares analysis confirms that energy use (ENUS), GDP per capita (GDPPC), government expenditure on environmental protection (GVEF), renewable energy (RENEN), and urbanization (URPN) significantly impact CO_2 emissions. The model demonstrates robustness, effectively handling outliers and providing reliable coefficient estimates, as shown by the high Rw-squared value. This robust analysis additionally highlights the significant role of urbanization in influencing CO_2 emissions, enhancing the overall understanding of its impact (Table 11).

Table (11): Robust Least Squares

Dependent Variable: CO_2
Method: Robust Least Squares

Variable	Coefficient	Std. Error	z-Statistic	Prob.
Ln FDEV	0.001615	0.000843	1.916450	0.0553
Ln ENUS	0.002078	2.09E-05	99.58201	0.0000
Ln GDPPC	9.84E-05	4.23E-06	23.24413	0.0000
Ln GVEF	-0.262919	0.037935	-6.930729	0.0000
Ln POLS	0.009356	0.019589	0.477611	0.6329
Ln RENEN	-0.021337	0.000831	-25.66396	0.0000
Ln URPN	0.004520	0.000831	5.436647	0.0000
C	0.199530	0.052119	3.828365	0.0001
	Robust Statistics			
R-squared	0.767916	Adjusted R-squared		0.762641
Rw-squared	0.998696	Adjust Rw-squared		0.998696
Akaike info criterion	477.1394	Schwarz criterion		510.2902
Deviance	22.03503	Scale		0.217863
Rn-squared statistic	234791.3	Prob(Rn-squared stat.)		0.000000

Source: Calculated using E-Views 12 software.

7. Conclusion and Policy Recommendations

Our comprehensive empirical investigation delves into the intricate relationships between various socioeconomic factors and CO_2 emissions in the Arab region, employing a range of econometric techniques including CCR, FMOLS, DOLS, and Robust Least Squares. Through rigorous analysis, we identify energy use, GDP per capita, government effectiveness, financial development, urbanization, political stability, and renewable energy as critical determinants shaping CO_2 emissions trends. The consistency of significant coefficients across these methodologies underscores the robustness of our findings, affirming the need for employing diverse approaches to ensure the reliability and comprehensiveness of policy-relevant insights in environmental research. Despite facing data limitations that led to the exclusion of certain GCC nations, our analysis focused on a subset of 12 Arab countries (Algeria, Egypt, Lebanon, Syria, Sudan, Saudi Arabia, Tunisia, Morocco, Iraq, the United Arab Emirates, Jordan, and Libya) meticulously chosen for their comprehensive data availability, shedding light on the regional dynamics of CO_2 emissions over the period from 1996 to 2022.

The implications drawn from our study extend beyond mere empirical findings, urging policymakers to adopt multifaceted strategies in tackling environmental challenges. Our findings advocate for the promotion of sustainable economic growth through the adoption of green technologies, energy efficiency measures, and environmentally friendly industrial practices. Moreover, our analysis highlights the significance of effective governance in shaping environmental policies and regulations, emphasizing the need for prioritizing good governance practices to facilitate the implementation of sustainable development initiatives. Furthermore, the importance of regional cooperation in addressing common environmental issues is underscored, urging Arab countries to collaborate in knowledge sharing and resource pooling to achieve collective sustainability goals. Strengthening data infrastructure emerges as a crucial imperative, emphasizing the necessity of enhancing data collection and dissemination mechanisms to inform evidence-based policy decisions and guide effective decarbonization efforts. In conclusion, our study not only provides valuable insights into the complex dynamics of CO_2 emissions in the Arab region but also serves as a clarion call for concerted efforts towards promoting sustainable development and environmental protection.

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