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Do Energy Efficiency and Technology Boost Sustainable Environment: Evidence from GCC Countries

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Abstract

Sustainable Environmental practices significantly reduce carbon emissions by ensuring the continuous use of materials and energy resources, thus aligning them with the decarbonization agenda's underlying objectives. Technological advancement has the potential to contribute significantly to this shift by streamlining resource flows, enhancing waste management procedures, and allowing more efficient energy consumption. Although Gulf Cooperation Council countries have experienced robust economic growth over the decades, rising pollution emissions and low renewable energy consumption have raised policymakers' concerns about this growth's long-term stability. In recent years, Gulf countries have paid significant concern to environmental matters and achieved carbon-free development. This study investigates the relationship between energy efficiency, technology, and sustainability, particularly emphasizing the green economy perspective. Carbon dioxide emission is taken as the dependent variable. Frontier Technology Readiness Index reflects the utilization of technology within economies. Energy efficiency is also considered, symbolizing the transition from fossil fuels to green energy due to technological progression in the energy sector. The findings suggest that factors such as the Frontier Technology Readiness Index, the energy intensity level of primary energy, and medium and high-tech manufacturing significantly harm the environment, while scientific and technical journal articles and agriculture significantly improve the environment over time. To improve Gulf Cooperation Council countries' environmental quality, policymakers must understand the factors causing climate change. This study gives policymakers helpful information about how to make the Gulf Cooperation Council community more sustainable by looking at energy efficiency, technology, and digital adaptation.

Keywords: *Energy Efficiency, Technology, Sustainable Environment, GCC countries.*

Introduction

Energy efficiency and technological advancement are the crucial paths to a sustainable environment [1-4]. Global warming began with the Global Industrial Revolution, which increased Carbon dioxide emission (CO2) because of the consumption of fossil fuels [5]. In this context, the Gulf Cooperation Council (GCC) nations have utilised substantial quantities of fossil fuels to support their development, leading to elevated CO2 emissions and a marked deterioration in environmental quality [6]. These countries warrant a particular focus on investigating the impact on environmental quality.

The issue of energy usage and environmental quality has involved many specialists who contend that expanding economic activities results in higher energy use [7], which is harmful to the environment. However, Karanfil [8] concluded that energy protection policies can minimize greenhouse gas emissions without affecting economic activities. As GCC countries are known for their high per capita energy consumption [9]. Recently, considerable actions to minimize greenhouse gas emissions and improve environmental quality were taken globally and within the context of GCC countries, Saudi Green Initiative in KSA [10], United Arab Emirates Vision's 2021 national agenda emphasizes enhancing the standard of air [11], Qatar's National Vision 2030 and Qatari Development Framework 2032 [12], Bahrain updated the national sustainable development strategy to safeguard human health as well as the marine and terrestrial environments in 2013 [13, 14], are examples of efforts to enhance environmental quality through reducing CO2 emissions.

However, GCC countries are facing different environmental crises [15]. Due to their economic strength, the GCC countries have the potential to play a more influential role, leading to improved environmental and life quality [16]. Given the benefits of green energy, the GCC should explore possibilities for enhancing energy efficiency as well as alternative energy sources, [17, 18]. Achieving a sustainable environment

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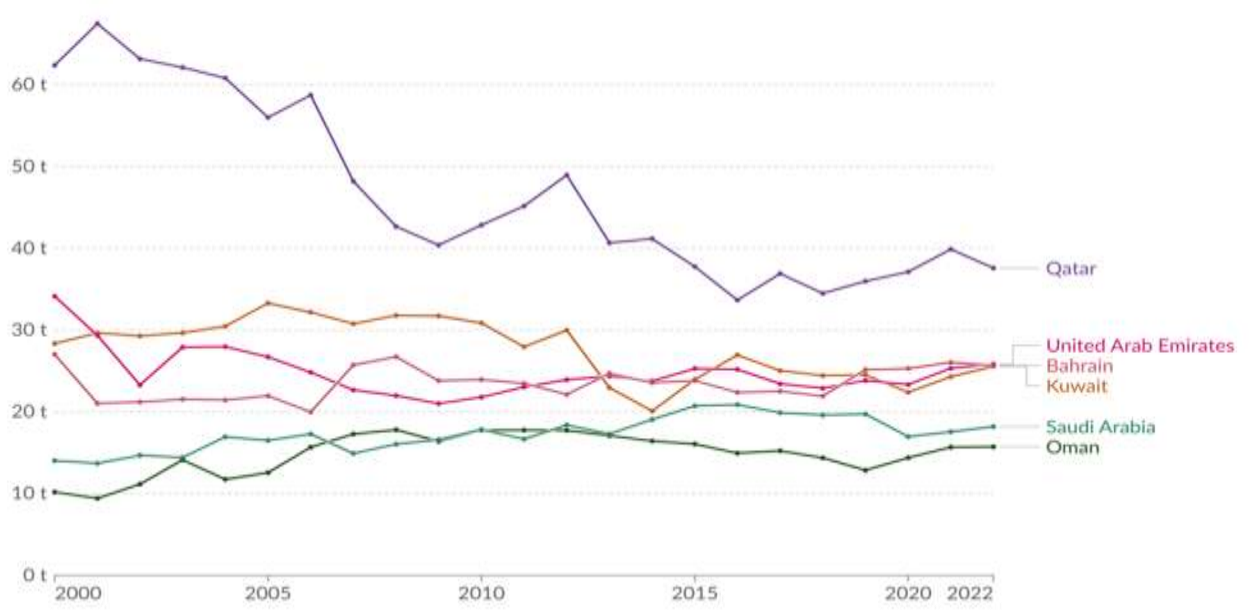
through energy efficacy has been a key defy for GCC states. A study by Nikbakht, et al. [19] offers a two-stage test for energy efficacy and environmental sustainability of GCC nations during the period 2000 to 2014. This study concluded that GCC countries could decrease energy consumption by up to 18%.

Figure 1 below shows Qatar leading the six GCC countries in per capita CO2 emissions from fossil fuels and industry, where Saudi Arabia and Oman are at the bottom. However, Qatar has exhibited a considerable rapid decrease in CO2 emissions during the last few years. It is important to note that though Saudi Arabia exhibited a higher percentage of CO2 emission than other GCC countries, considering the population size and growth, the study finds that per capita CO2 emission is much different and stands in the fifth position.

Figure 1 Per capita CO2 emissions from fossil fuels and industry GCC countries 2000-2022



Source: Global Carbon Budget (2023), OurWorldData.org (Access 8 September 2024)

The graph reveals the economic implications of per capita CO_2 emissions trends for the GCC countries, particularly regarding their resource-driven economies, diversification efforts, and potential costs of inaction on environmental issues. The discussion of an economic analysis of each country's trends

Qatar with high emissions and slow decline: Qatar's consistently high per capita CO_2 emissions, though decreasing, indicate a strong dependence on carbon-intensive industries like oil and natural gas extraction. This reliance brings short-term economic benefits in terms of high GDP per capita but poses long-term economic and financial risks. As global demand shifts toward low-carbon energy, Qatar may face increased pressure to diversify its economy to avoid potential income loss. Given its current emissions levels, Qatar will likely face high transition costs if it accelerates decarbonization. Investment in green technology, renewable energy, and energy-efficient infrastructure could be costly but necessary to ensure economic resilience.

The United Arab Emirates and Bahrain with remarkable stability: The stable emissions per capita in the UAE and Bahrain suggest that economic growth in these countries has not led to a proportional increase in CO_2 emissions. This stability indicates early efforts to diversify beyond hydrocarbons, with both nations investing in sectors like tourism, finance, and, more recently, green energy. Maintaining stable emissions helps avoid escalating climate-related economic costs, such as health impacts and infrastructure damage. Investing in renewable energy and sustainable development further enhances their attractiveness as business and tourism hubs, aligning with their economic diversification goals.

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Kuwait with high fluctuation and high emissions: Kuwait's fluctuations in emissions without an apparent long-term decline suggest limited progress in decoupling economic growth from emissions. This pattern may reflect Kuwait's continued reliance on fossil fuel exports with fewer diversification initiatives than some other GCC countries. High emissions can increase Kuwait's exposure to international climate regulations, carbon tariffs, and economic risks tied to fluctuating oil demand. Without substantial shifts toward low-carbon technologies, Kuwait risks stranded assets in the oil sector and lost revenue as the global economy transitions.

Saudi Arabia characterized with gradual decline due to policy shifts: The gradual decline in Saudi Arabia's per capita CO_2 emissions aligns with its Vision 2030 objectives, which aim to diversify the economy, reduce dependence on oil, and create new revenue sources. This downward trend could indicate early returns from investments in renewable energy, energy efficiency, and non-oil sectors like technology and tourism. By reducing emissions, Saudi Arabia is positioning itself to be more competitive in a low-carbon global economy. This may help attract foreign investment, reduce vulnerability to carbon tariffs, and create jobs in emerging sectors, supporting economic stability even as oil demand potentially decreases.

Oman with low and stable emissions: Oman's relatively low and stable emissions per capita reflect a less intensive industrial base and potentially more energy-efficient practices. This could be partly due to a lower population growth rate and limited industrial expansion compared to other GCC countries. While Oman's lower emissions position it favorably in terms of international climate commitments, its smaller economy might face challenges in financing large-scale renewable energy projects. However, maintaining low emissions can enhance its regional competitiveness in a low-carbon economy.

The analysis of data from the GCC countries reveals their significant contribution to global CO2 emissions [20]. Most of these emissions originate from the energy extraction sectors, primarily from oil and gas. Figure 2 shows CO2 emissions by fuel or industry type in GCC countries from 2000 to 2022.

The GCC's high carbon intensity reflects their economies' reliance on oil and gas. This exposes them to risks, including the potential for stranded assets as the world moves away from fossil fuels and economic penalties under global climate agreements. While reducing emissions requires significant upfront investment, it offers benefits in terms of economic stability, resilience to oil price shocks, and alignment with global sustainable finance trends. Moving towards renewables, improving energy efficiency, and diversifying sectors would protect these economies from the volatility of fossil fuel markets. For many GCC countries, decarbonization aligns with broader diversification objectives. Investments in clean technology, sustainable infrastructure, and low-carbon sectors support long-term economic growth while attracting international investment.

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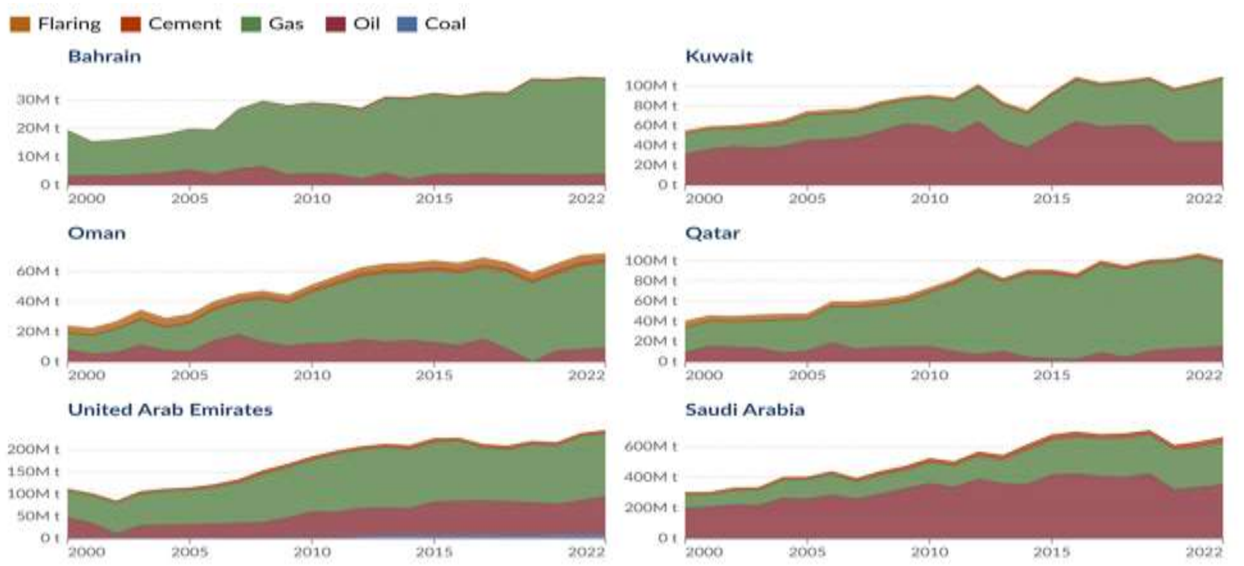
Figure 2: CO2 emissions by fuel or industry type GULF countries 2000-2022



Source: Global Carbon Budget (2023), OurWorldData.org (Access 8 September 2024)

Al-shammari, et al. [21] talked about the connection between technology and a sustainable environment in GCC countries. They wanted to explore the connection among ICT, CO2 emissions, economic growth, trade, and the total population of GCC countries. Their results showed that CO2 emissions and ICT are positively significant, and they concluded that ICT in GCC countries should be switched to green technology.

The current study intends to contributes to the field's current literature. It examines the effects of energy efficiency and technology on sustainable environments in GCC countries. This study investigates the impact of energy efficiency, digital adaptation, and technological advances on sustainable environments, considering the present literature. Using the environmental Kuznets curve (EKC) theory, this paper looks at CO2 emissions as a sign of a sustainable environment. This relationship is discussed in several papers examining the demand side of natural resources.

Following Chen, Alharthi, Zhang and Khan [3], [22] and [23] the study uses energy intensity as a measure of energy efficiency. The study expects energy production, transportation, and consumption to impact the GCC environment [24, 25]. Furthermore, energy production in GCC countries is associated with water pollution through oil spills. This study uses the Frontier Technology Readiness Index as an indicator of digital adaptation and, consequently, technological advancement [26].

Milindi and Inglesi-Lotz [27] and Delanoë, et al. [28] use scientific and technical journal articles as indicators of green technology in GCC countries, highlighting the significance of human capital, public awareness, and scientific and technical knowledge in reducing CO2 emissions. Moreover, the authors have added a variable medium and high-tech manufacturing value added (% manufacturing value added) technological advancement in the manufacturing sector. In addition to agriculture, forestry, and fishing, a value-added component has also been included.

The remaining sections of the paper are arranged as follows: Section 2 delivers an extensive review of the preceding literature relating to the current topic. Section 3 delineates the employed method, outlines the data description and sources, and explains the econometric results and discussion in Section 4. Finally, Section 5 concludes, discusses potential policy implications, and offers recommendations for future research based on the main findings.

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Literature Review and Hypothesis Development

GCC countries, like global nations everywhere, aim to attain environmental sustainability and carbon neutrality while maintaining the goal of achieving growth for their economies and societies. Many scholars have realized the unfavorable leverage of some economic activities on climate change [29]. Dzwigol, et al. [30] tried to explore the effect of environmental rules, green energy, and energy efficiency on green economic expansion. The results of this research emphasize the nonlinear effect of environmental rules on a country's sustainable economic growth, besides a piecemeal rise in energy efficiency. More Investigation is needed to explain the relationship between energy efficiency, Technology, agriculture and sustainable development**.**

Energy Efficiency and Sustainable Environment

Numerous studies have looked into the divergent relationships between energy intensity and environmental quality. The study strives to achieve energy efficiency, boost environmental sustainability, and mitigate CO2 emissions. A study by Khurshid, Fiaz, Ali and Rashid [1] recognized that energy efficiency negatively affected environmental sustainability by increasing Pakistan's ecological footprint. Alam, et al. [31] inspect the influences of energy efficiency on Oman's outlooks for achieving green environmental development and discover that improving energy efficiency promotes carbon productivity in Oman. Adebayo and Ullah [32] examined the time and frequency-based interactions between CO2 emissions and selected variables over the period 1990–2020. Their empirical findings demonstrated a substantial negative association between CO2 emissions and energy efficiency metrics throughout short-, medium-, and long-term frequency domains.

Nonetheless, a large body of research has found a beneficial relationship between environmental sustainability and energy efficiency. By analyzing the impact of energy efficiency on ecological sustainability and economic development in the top ten energy-efficient economies between 1990 and 2019, Chen, Alharthi, Zhang, and Khan [3] validated these findings by using energy depletion, energy security, and energy access as moderating factors. Their findings show that CO2 emissions, ecological impact, and economic development are strongly correlated with energy intensity, security, and accessibility. Similarly, Wenlong et al. [33] attempted to analyze the environmental impact of trade openness, technical advancements, energy efficiency, and institutional quality in ten Asian nations between 1995 and 2018. Their findings show that technical advancements and energy efficiency have a favorable impact on environmental quality.

The effects of nuclear energy, energy efficiency, renewable energy, and financial globalization on environmental quality are also valued by Jin et al. [34]. According to the study's findings, research and development in energy efficiency and clean energy both improve ecological quality, which in turn improves environmental quality. Using data from 1990 to 2020, Liu et al. [35] investigate the co-movement between CO2 and coal efficiency, climate policy uncertainty, green energy, and green innovation. Their research showed that lowering CO2 emissions is influenced by coal efficiency. Furthermore, by lowering CO2 over the short and medium term, green innovation advances ecological refinement. Zhang et al.'s study [36] looked into the connections between carbon emissions, energy efficiency, and the digital economy. According to the study's findings, carbon emissions are compressed by China's digital economy. A required partial moderator between the two is energy efficiency. Carbon emissions can be decreased through increased energy efficiency.

Furthermore, Sultana and Rahman [37] examined the relationship between energy intensity and the environment. Their findings highlight the impact of population, GDP, green energy, fossil fuels, energy intensity, and the service sector on environmental quality in MENA nations. Their results show that energy intensity contributes to environmental pollution. Singh et al. [38] searched the effectiveness of financial inclusion, green technology, and energy efficiency on sustainable development. The findings show that financial inclusion rises with higher quantiles, suggesting that countries with already high ecological footprint standards are more likely to encourage a higher ecological footprint than those with lower standards.

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In addition, they highlighted the importance of transitioning industrial economies to carbon-free technologies. Another study by Zakari, et al. [39] references twenty Asian and Pacific (AP) economies covering the period 2000 to 2018 and shows a positive relation between sustainable economic growth and energy efficiency. Rehman Khan, et al. [40] discussed the long-term relationship between green economic growth and some factors, applying annual data from 1990 to 2020 for OECD countries. Their research identifies the importance of energy efficiency, renewable energy, and technology as positive predictors of green economic growth. There are prominent diversities among investigators who have studied the relation between energy efficiency and CO2. likewise, researches have missed in order to realize the importance of energy efficiency on the environmental quality of GCC nations. Thus, the present study hypothesized the following:

Hypothesis 1

Energy efficiency significantly mitigates CO2 emissions in GCC economies.

Technology and Sustainable Environment

The study expects that technology and technical advancements will have either a beneficial or detrimental effect on sustainable environments. Su, et al. [41] Research returns uncover that technological innovation has beneficial and adverse impacts on CO2. The adverse effect implies that technological innovation is an effective method for reducing CO2 emissions, which is in line with the energy-environment model. However, the positive impact suggests that technological innovation will result in greater energy consumption and pollution. Conversely, the negative correlation between CO2 and technological innovation suggests that governments must implement more environmentally friendly policies to reduce carbon pollution. Milindi and Inglesi-Lotz [27] investigate the relationship between carbon emissions and technological advancement using six different proxies for technology. Their findings indicate that ICT indicators appear to be a successful instrument to lower CO2 emissions. In contrast, spending on research and development and patents have no significant influence on CO2, total factor productivity boosts carbon emissions, while science and technology publications exhibit a negative impact on CO2 emissions.

Radulescu, et al. [42] examined how green technology innovation, energy efficiency, and ecological regulations affect carbon emissions in different regions of China. Their results showed that a 1% increase in GDP corresponds to a 0.08% increase in CO2 emissions across Thirty Chinese regions. Green energy and energy efficiency decrease CO2 emissions. Renewable energy and energy efficiency decrease CO2 emissions. A study by Adebayo, et al. [43] inspected the influence of investing in energy efficiency research and development, information and communication technologies, and changes in structure on CO2 emissions and ecological footprint. Their returns validated the favorable effect of investments in energy efficiency research and development, information and communication technology developments, and structure changes in reducing CO2 emissions and ecological footprint. In their 2023 study, Wang, et al. look at how changes in technology, financial growth, renewable and nonrenewable energy, and foreign direct investment (FDI) affect the environmental impact of fourteen developing European countries. Their research shows that financial growth, nonrenewable energy use, and FDI lead to more environmental degradation over time, while renewable energy and new technologies help slow it down.

Chien, et al. [44] examine the function of technological progress, globalization, and green energy on mitigating environment devolution in Pakistan. Their findings reveal that technical progress and renewable energy have an inverse relationship with environmental retrogression. As well the results of Aneja, et al. [45] on G-20 nations from 1992 to 2018 detected that clean energy and technological advances, especially green technologies, contribute greatly to ecological sustainability. Sarabdeen, et al. [46] study's findings reveal that digital technology improves environmental quality. Alofaysan [47] examined the changeable effect of clean energy and green innovations on the carbon footprint of selected MENA countries during the period 2000 to 2020. The findings revealed that the increase in green inventions and clean energy sources improves environmental sustainability in both the short and long term. Elmonshid, et al. [48] researched the impact of some economic indicators on CO2 emissions in GCC nations during the period

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2001 to 2021. Their returns show that patents are positively related to CO2 emissions, emphasizing the significance of directing innovative technology to enhance environmental sustainability.

Several research papers attempt to expose how clean technology will influence CO2 emissions. Prior research frequently used spending on R&D activities to represent innovation in studies that try to quantify its environmental traces. Different studies have come to conflicting findings [4, 49-51]. Based on the above literature, the hypothesis 2 is formulated as follows:

Hypothesis 2

Technological advancement significantly mitigates the CO2 emissions of GCC economies.

Agriculture, Manufacturing, and Sustainable Environment

Aziz, et al. [52] explored the environmental impacts of agriculture in GCC countries. Their findings signaled that agriculture has no significant effect on environmental quality. Another study by Asumadu-Sarkodie and Owusu [53] investigated the effect of agriculture on environmental pollution in Ghana. Their outcome showed an inverse relation between agriculture and carbon dioxide emissions. Likely, Adedoyin et al. [54] explored an adverse and significant link between agricultural value-added and CO2 emissions in sub-Saharan Africa. Zeng et al. [55] inspected the effect of technical innovation and renewable energy on CO2 emissions in BRICS countries; they found that technological innovation significantly fosters CO2 emissions while energy efficiency significantly drops carbon emissions.

Alfantookh, et al. [56] discussed the effects of manufacturing on the environment. Their findings did not affirm the short term impact of industry on CO2 emissions. Yet, there are hints of positive impacts in the long term. Furthermore, Ghosh, et al. [57] inspected the influence of high-tech industries on CO2 and environmental footprint. Their long-term results showed that high-tech industries have a significant environmental welfare-boosting effect. Burmaoglu, et al. [58] found that creating circular business models is necessary to ensure industrial circularity. To improve the circular economy's profitability, effectiveness, and transparency, digital manufacturing should be combined with the context of industrial ecology and recycling ideas. However, the role of AI models in actualizing the decarbonization agenda through improved performance of the circular economy within the context of built environment is still insufficiently researched. Therefore, this study aims to close the knowledge-practice gap by utilizing worldwide data from 79 countries and applying fixed-effect and random-effect estimates. In their study, Khurshid, Fiaz, Ali and Rashid [1] look at how natural resource rents, high-tech exports, renewable energy, GDP, and corruption affect CO2 emissions for 141 developing countries from 2000 to 2021. Their findings state that the export of high-technology increases CO2 emissions. The empirical and theoretical studies reviewed supported the idea that energy efficiency and technology could significantly sustain the environment. The hypothesis 3 can be stated as follows:

Hypothesis 3

Agricultural and manufacturing development significantly affect the CO2 emissions of GCC economies.

Research gap

Previous extensive reviews of the present literature highlighted several factors that affect CO2 levels and environmental quality. The fundamental purpose of the current study is to address the gap in the existing literature by focusing on GCC countries. Furthermore, the current study identifies the principal contributors to CO2, particularly in the GCC countries. The existing studies primarily focus on traditional factors, neglecting recently emerging ones such as the Frontier Technology Readiness Index (FTRI). This study might fill this gap by considering the influence of FTRI on environmental quality in GCC countries.

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Methodology and Data

Data

The study uses a balanced longitudinal dataset for 6 GCC countries: Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates, covering the period 2008-2022. The selected variables, list, measure, and sources are presented in Table 1 below. Data were acquired from internationally recognized databases such as the World Bank and UNCTAD. All selected variables are transferred to logarithmic form to compress scale, reduce skewness, and promote symmetry in distributions [37].

Table (1) Variable Description and Sources of Data

Variables	Description	Indicator	Source
Carbon dioxide emissions	CO2 emissions (kg per 2015 US$ of GDP)	Environmental quality	WB-WDI
Frontier Technology Readiness Index (FTRI)	Implementation ICT, labor skills, Research Development, manufacturing capability, and financial access.	Digital adaptation	UNCTAD
Energy Efficiency	Energy intensity level of primary energy (MJ/$2017 PPP GDP)	Energy efficiency	WB-WDI
Technology	Scientific and technical journal articles per person	Technological advancement	WB-WDI
high-tech manufacturing	Medium and high-tech manufacturing value added (%value)	Industrial development	WB-WDI
Agriculture	Agriculture, forestry, and fishing, value added (% of GDP)	Agricultural development	WB-WDI

Author's presentation

Table 2 provides a summary of the descriptive data, including the central tendency represented by the mean and the data distribution represented by the variable standard deviation values. The mean of 3.0545 indicates the average log of CO_2 emissions across the observations. A relatively low standard deviation of 0.2684 suggests that there is limited variation in CO_2 emissions within the sample, meaning the data points are relatively close to the mean. The average FTRI is around -0.6669. The moderate standard deviation (0.1886) indicates that FTRI shows some variability, although not extreme. The negative mean and range suggest that FTRI, on average, is less than one in raw terms, pointing to a relatively low level of FTRI in comparison to the size of the economy. The average EE level in log terms is 1.9219, with a low standard deviation of 0.1735, indicating that EE levels are relatively stable across the observations. This suggests limited variation, likely implying a consistent approach or capacity for energy efficiency across the sample. SJA with a mean of -8.2999, appears to be quite low. The relatively higher standard deviation (0.5139) indicates greater variation in SJA among the observations. The average level of HTM is 3.4504, with a standard deviation of 0.3591, indicating moderate variability. This spread could suggest differences in the capacity or emphasis on HTM across the sample, with some countries or regions possibly more advanced in this area than others. The mean for ARG is -0.4744, with a high standard deviation of 0.9850, indicating significant variability in ARG. This wide range, from -2.3624 to 1.0853, suggests that ARG's economic significance varies greatly within the sample, potentially due to differing levels of agricultural development, climate conditions, and economic reliance on agriculture.

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Table (2) Descriptive Analysis

Variable	Obs	Mean	Std. Dev.	Min	Max
lnCO2	90	3.0545	0.2684	2.6535	3.6784
lnFTRI	90	-0.6669	0.1886	-1.2040	-0.3567
lnEE	90	1.9219	0.1735	1.6034	2.3370
lnSJA	90	-8.2999	0.5139	-9.4311	-6.6728
lnHTM	90	3.4504	0.3591	2.6542	4.1995
lnAGR	90	-0.4744	0.9850	-2.3624	1.0853

Author’s calculation using STAT 13.

Table 3 offers the pairwise correlation matrix, the extent of association between −1 and +1; the results reveal no high correlation between the selected variables.

Table (3) Correlation Analysis

Variables	lnCO2	lnFTRI	lnEE	lnSJA	lnHTM	lnAGR
lnCO2	1.0000					
lnFTRI	-0.2884	1.0000				
lnEE	0.1154	-0.1130	1.0000			
lnSJA	0.3983	0.3175	-0.1356	1.0000		
lnHTM	0.2134	0.0584	-0.2786	0.5873	1.0000	
lnAGR	-0.9114	0.2755	-0.3299	0.1964	0.0161	1.0000

Author’s calculation using STAT 13.

Methodology

The study calculated the logarithmic form of the following econometrics model to look at the short- and long-term links between technology, energy efficiency, and a sustainable environment:

$$CO2_{it} = f(EE_{it}, FTRI_{it}, SJA_{it}, HTM_{it}, AGR_{it}) \quad (1)$$

Where: i = country , t time (year)

CO2 represents CO2 emissions (kg per 2015 US$ of GDP), FTRI stands for Frontier Technology Readiness Index, which measures a country's readiness to adopt and adapt frontier technologies [26]. EE

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represents the energy intensity level of primary energy (MJ/$2017 PPP GDP), SJA represents the number of scientific and technical journal articles per person, HTM stands for medium and high-tech manufacturing value added (% of manufacturing value added), and AGR represents the value added to agriculture, forestry, and fishing (% of GDP).

$$CO2_{it} = \beta_0 + \beta_1 EE_{it} + \beta_2 FTRI_{it} + \beta_3 SJA_{it} + \beta_4 HTM_{it} + \beta_5 AGR_{it} + \varepsilon_{it} \quad (2)$$

As the study uses panel data from 9 countries covering the period (2000-2021), this study applies the pooled mean group (PMG) approach. One advantage of the Pooled Mean Group (PMG) methodology is that it identifies long- and short-term relations among the variables under consideration. Moreover, PMG ARDL methodology considers cross-sectional dependency. Another advantage of using the Panel ARDL technique in this study is the fact that it explores the co-integration relationship between the variables, despite the degree of cointegration I(0) or I(1) [59, 60]This approach is also useful for small samples. The ARDL approach's mathematical model includes getting empirical estimates for both the short—and long-term effects and the rate at which the long-run equilibrium is reached through the lagged error correction term (ECT).

Before performing the PMG ARDL, the paper performed some diagnostic procedures, such as correlation analysis, cross-section dependence, and unit-root tests. First, the paper tested the cross-sectional dependence CSD using Pesaran [61] scaled LM, and Pesaran, et al. [62] Bias-corrected scaled LM. The CSD test's success was demonstrated in both the short and long-panel datasets.

Breusch and Pagan [63] test statistics (LM):

$$LM = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} T_{ij\hat{P}^2{}_{ij}} \rightarrow X^2 \frac{N(N-1)}{2} \quad (3)$$

Pesaran [64] scaled LM test statistics:

$$LM_s = \sqrt{\frac{1}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} T_{ij\hat{P}^2{}_{ij}} \rightarrow N(0,1) \quad (4)$$

Pesaran [64] CD test Statistics:

$$CD_P = \sqrt{\frac{2}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} T_{ij\hat{P}^2{}_{ij}} \rightarrow N(0,1) \quad (5)$$

Pesaran, Ullah and Yamagata [62] Bias-corrected scaled LM test Statistics:

$$LM_{BC} = \sqrt{\frac{1}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} T_{ij\hat{P}^2{}_{ij}} - \frac{N}{2(T-1)} \rightarrow N(0,1) \quad (6)$$

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Where $\hat{P}^2{}_{ij}$ the correlation coefficient between the residuals.

Then, panel unit root tests were performed to check the variables' stationery. Following Pesaran [65] the study employed a first-generation panel unit root test based on cross-section dependence test results.

Given that the selected variables are I (1), the study proceeded to examine the series of variables for cointegration to verify the presence of a long-run equilibrium relationship between the variables. The study follows the Pedroni [66] test; this test deals with heterogeneity and interdependence [67]. Pedroni [66] test for co-integration offers two significant outputs: (1) within the dimension, which consists of panel v-statistic, panel-rho statistic, panel PP-statistic, and panel ADF-statistic. (2) Between dimensions, there are three outputs: group-rho statistic, group-PP statistic, and group-ADF-statistic.

$$CO2_{i\,t} = \alpha_i + \rho_{it} + \sum_{j-1}^{M} \beta_{j\,i} Xj_{i\ t} + u_{i\,t} \tag{7}$$

Also, Kao Co integration test is provided as a robustness test.

Next to that, the study applies the Panel ARDL method suggested by Pesaran, et al. [68]Panel ARDL is a popular approach for locating the long-run and short-run relations between variables. This method's robustness in capturing both short-run and long-run dynamics among energy efficiency, technology, and sustainable environment in GCC countries makes it suitable for this study.

In addition, this method accommodates cross-section heterogeneity. Another important aspect of this method for this study is that the variables are stationary at I(0), I(1), or a mix of the two, which is common in macroeconomic datasets. Finally, the error correction model (ECM) in the Panel ARDL model offers unambiguous conclusions about the velocity of adjustment toward long-run equilibrium, guiding policymakers in GCC countries on how to address environmental sustainability issues.

The basic econometric model for this study was later transformed into the following PMG:

$$\Delta CO2_{i\,t} = \vartheta(CO2_{i\,t-1} - \theta X_{i\,t}) + \sum_{j=0}^{q-1} \Delta X_{i\,t-j}\beta_{i\,j} + \sum_{j=1}^{p-1} \gamma_{i\,j}\beta_{i\,j}\,\Delta CO2_{i\,t-1} + \varepsilon_{i\,t} \tag{10}$$

where, $CO2_{i\,t}$ denotes the dependent variable, $X_{i\,t}$ denotes explanatory and control variables, $\varepsilon_{i\,t}$ denotes the error term. The last step is followed by PMG Models; the study uses the Dumitrescu Hurlin Panel Causality Test as a robust method to detect possible casual relationships among the selected variables. A causality test is desired to define the direction of the causal relations. Dumitrescu and Hurlin [69] extended the Granger causality test for panel data, creating a more robust bootstrap panel causality test. They derived the test statistics and probability values of the Dumitrescu and Hurlin tests using the Monte Carlo simulation. Dumitrescu and Hurlin test statistics are the sum of individual Wald statistics. The following equations are Wald statistics for panel causality tests.

$$CO2_{i\,t} = \alpha_i + \sum_{j-1}^{p} \gamma_{i\,j} CO2_{i\ t-\mathrm{j}} + \sum_{j-1}^{p} \theta_{i\,j} \mathrm{X}_{i,t-j} + u_{i\,t} \tag{11}$$

$$W_{NT}^{Hnc} = \mathrm{N}^{-1} \sum_{i-1}^{N} W_{i\,t} \tag{12}$$

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$$Z = \sqrt{(\frac{N}{2P})\frac{T-2P-5}{T-P-3}} \times \left(\frac{T-2p-3}{T-2P-1}\overline{W} - P\right) \quad (13)$$

Table (4) Cross-Sectional Dependence Tests

Tests	Statistics	P values.
Breusch-Pagan LM	20.9645	0.1380
Pesaran scaled LM	1.0890	0.2762
Pesaran CD	0.9223	0.3564

Source: Author's calculations.

Table 4 show that the Breusch-Pagan LM test checks for cross-sectional dependence in large panels, especially when the sample size is large relative to the number of units. The test's p-value of 0.1380 is above the conventional significance levels, indicating that we do not reject the null hypothesis of no cross-sectional dependence. This suggests that the variables in each unit are not significantly correlated with those in other units, meaning that the economic variables in one country or region do not strongly influence the others. The Pesaran scaled LM, the p-value of 0.2762 again exceeds common significance thresholds, supporting the null hypothesis of no cross-sectional dependence. This result implies that, on average, the economic behavior or outcomes in one unit are relatively independent of those in other units in this dataset. The results from all three tests consistently show that there is no statistically significant cross-sectional dependence across the units in this panel dataset. Economically, this implies that each country or region in the sample behaves independently in terms of the variables under study. In practical terms, this could mean that economic, environmental, or policy changes in one country or region do not directly affect others in the sample.

The absence of cross-sectional dependence is valuable for modeling, as it suggests that each unit can be analyzed independently without worrying about spillover effects. However, it also means that regional integration or economic interdependence may be limited, which could influence policies aimed at regional cooperation or shared economic strategies.

Empirical Results and Discussion

Due to the absence of cross-section dependence, the study ran the first-generation unit root test; Levin, Lin, Chu, Im, Pesaran and Shin, ADF – Fisher, and PP-Fisher [70]. The results are reported in Table 5.

Table 5 Unit Root Test results

	Levin, Lin & Chu t*		**Im, Pesaran and Shin W-stat**		**ADF - Fisher Chi-square**		**PP - Fisher Chi-square**	
	Level	**First difference**	**Level**	**First difference**	**Level**	**First difference**	**Level**	**First difference**

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lnCO2	-1.2774	-1.7381**	-0.8346	-2.3672***	16.1324	25.3182**	16.4961	44.0983***
lnFTRI	1.8553	-2.96626***	2.4485	-4.03117***	2.48204	38.3139***	10.1142	94.6336***
lnEE	-3.1745***	-5.7834***	-2.7155***	-4.2287***	28.5035***	40.0197***	27.1657***	85.4669***
lnSJA	-5.3263	-1.2817	2.6627	-1.4613*	2.5718	18.3819	2.8421	41.9524***
lnHTM	-2.0441**	-6.4385***	-1.0662	-4.8726***	16.1559	45.5534***	14.2820	69.5485***
lnAGR	-1.9843**	-5.3263***	-1.8755**	-4.0781***	22.8312**	38.8782***	38.4457***	47.9821***

Source: Author's estimates. Note: *** denote 1%, and **, denote 5% significant levels.

Table 5 shows the outcomes of panel unit root tests. All of the chosen variables were I(1) at 1%, 5%, and 10% significance levels for at least two of the tests.

Pedroni Test	**Statistic**	**Weighted Statistic**
Panel v-Statistic	-0.5713	-0.4835
Panel rho-Statistic	1.6210	1.7326
Panel PP-Statistic	-1.2463	-1.4002*
Panel ADF-Statistic	-1.4541*	-1.6397*
Group rho-Statistic	2.7910	
Group PP-Statistic	-1.6917**	
Group ADF-Statistic	-1.8027**	
KAO Test		
ADF	-2.6919**	

Source: Author's estimates. Note that, ** denote 5%, and * denote 10% significant levels.

Researchers using Pedroni integration tests found that the variables are linked, especially in the Panel PP-Statistic and Panel ADF-Statistic results. This is true even though the autoregressive coefficients may change within and between dimensions. The results of the KAO test confirmed the co-integration among the variables. The Pedroni and KAO test results justified an investigation of the long-run estimates; the study uses PMG ARDL to determine the long-run relationship [71].

Table 6 Panel ARDA (PMG) Tests

	Coefficient	**t-Statistic**
Long Run Equation		
lnFTRI	0.4881***	12.5499
lnEE	0.8713***	24.1847
lnSJA	-0.1288***	-17.9052
lnHTM	0.0773***	5.0011
lnAGR	-0.1235***	-8.1287
Short Run Equation		
COINTEQ01	-0.6072**	-1.9423
lnFTRI	-0.0407	-0.6174

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lnEE	-0.1434	-0.4670
lnSJA	0.0167	0.6808
lnHTM	0.1501	1.5430
lnAGR	-0.0048	-0.0747
C	0.1438	1.1082

Source: Author's estimates. Note that, *** denote 1%, and ** denote 5% significant levels.

Table 6 shows the PMG ARDL model estimation results. It shows that most explanatory variables have a long-run relation with the dependent variable. In the long term, FTRI, EE, and HTM have a positive and significant effect on CO2 emissions, while SJA and AGR have a negative and significant effect.

The coefficient of FTRI is 0.4881, indicating that a 1% increase in FTRI results in a 0.4881% increase in CO2 emissions, under the assumption that all other factors remain constant. The result of the present investigation is not supported by [26, 46, 72].

Findings from the EE show that a 1% increase in the energy intensity level of primary energy causes 0.8713 % more CO2 emissions. These findings agree with those of Wenlong, Tien, Sibghatullah, Asih, Soelton and Ramli [33], Sultana and Rahman [37], and Chen, Alharthi, Zhang and Khan [3], who found that energy intensity is linked to higher CO2 emissions. This positive correlation between CO2 emissions and energy intensity is not consistent with the results of Khurshid et al. (2024).

The HTM results show that a 1% increase in medium—and high-tech manufacturing value added increases CO2 emissions by 0.0773%. Alfantookh, Osman and Ellaythey [56] support this positive correlation, which contradicts the conclusions of Ghosh, Adebayo, Abbas, Doğan and Sarkodie [57].

The long run coefficient of SJA equals -0.1288, pointing out that a 1% increase in SJA is accounted to a decrease CO2 emissions by -0.1288%; this finding is supported by Milindi and Inglesi-Lotz [27]. The coefficient of AGR is -0.1235, pointing out that a 1% increase in AGR reduces CO2 emissions by -0.1235%. Several studies, including Asumadu-Sarkodie and Owusu [53] and Adedoyin, Alola and Bekun [54] also supports the negative relation between agriculture and CO2 emissions. The ECM coefficient is negative -0.6072 and significant at 5%, supporting the long-run relations. This result indicates that the annual speed of adjustment to long-run equilibrium is about 61%.

To accomplish the net-zero CO2 emission target and promote sustainable environment in GCCS states, the PMG model findings suggests implementing policies that boost scientific and technical research through encouraging clean technology, and ensuring sustainable agriculture. Meanwhile greater effort should be directed to improve the efficiency of energy use. GCCs nations have to mitigate the environmental effects of nonrenewable energy sources, supporting clean technology deployment, and utilizing renewable energy sources. Nonetheless, their impact is significant enough to promote ecological sustainability.

The study follows the PMG models and uses the Dumitrescu Hurlin Panel Causality Test as a robustness mode to detect the possibility of casual relationships among the selected variables. Table 7 below displays the findings of the Dumitrescu Hurlin Panel Causality Test [69].

Table 7 Dumitrescu Hurlin Panel Causality Test

H0	W.Stat	Zbar.Stat	Prob	
LOG(FTRI) does not Granger cause LOG(CO2) LOG(CO2) does not Granger cause LOG(FTRI)	3.5192 2.7136	1.8606 0.8740	0.063 0.382	→

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LOG(EE) does not Granger cause LOG(CO2) LOG(CO2) does not Granger cause LOG(EE)	3.6903 1.7404	2.0702 -0.3179	0.038 0.751	→
LOG(SJA) does not Granger cause LOG(CO2) LOG(CO2) does not Granger cause LOG(SCJA)	10.8923 4.0122	10.8908 2.4644	0.0000 0.014	↔
LOG(HTM) does not Granger cause LOG(CO2) LOG(CO2) does not Granger cause LOG(HTM)	4.3238 2.9590	2.8460 1.1746	0.004 0.240	→
LOG(AGR) does not Granger cause LOG(CO2) LOG(CO2) does not Granger cause LOG(AGR)	7.5893 3.4854	6.8455 1.8192	0.000 0.069	↔

Source: Author's estimates.

Dumitrescu Hurlin causality testing examines the causative relationship between carbon dioxide CO2 emissions and various environmental and energy efficiency and technology advancement variables (FTRI, EE, SCJA, HTM, and AGR) in GCCs nations. The outcomes outlined in table 7, reveal bidirectional granger and unidirectional granger causality. There is marginal evidence that (FTRI) influence CO2 emissions, but no reverse relationship is found. Energy efficiency improvements are shown to cause CO2 emissions, but the reverse is not true. Moreover, medium and high-tech manufacturing value added influences CO2 emissions, but not the reverse. These findings demonstrate that policy makers ought to emphasize implementation of (ICT), improving labor skills, investing in research and development, enhancing manufacturing capacity, and ensuring financial inclusion, energy-efficiency, improvements medium and high-tech manufacturing, as strategic measures for boosting the environment quality of GCCs nations'.

There is bidirectional solid causality between Scientific and technical journal articles SJA and CO2 emissions, and between agriculture and CO2 emissions. They mutually influence each other, though CO2's effect on agriculture is marginally weaker. Consequently, SJA and AGR can estimate the prospective future amount of CO2 emissions in GCCS nations, whereas CO2 emissions can also be used to predict SJA and AGR.

These findings align well with existing literature on the causality between technological advancement factors and CO2 emissions, though with some distinctions in the direction and strength of causality. The bidirectional relationships observed between agriculture AGR and CO2 emissions highlight the complexity of environmental challenges in the studied regions. The unidirectional causality from energy efficiency to CO2 emissions underlines the importance of advancing sectors to mitigate emissions. These results provide a foundation for policy discussions, particularly emphasizing the need for proactive environmental policies to control emissions in emerging economies.

Conclusions and Policy Implications

Conclusion

Reducing CO2 emission is a crucial globe development challenge facing nations globally presently. The global focus is largely on the effective lowering of environmental degradation and its accompanying expenditure. Technology development and energy efficiency are the two main approaches ahead with a sustainable environment. With the advent of the industrial revolution and the use of fossil fuels, CO2 levels rose, causing global warming to start [73], [74] and [75]. The GCC countries' substantial dependence on fossil fuels has significantly declined environmental quality and elevated CO2 emissions. Attaining an environmentally sustainable framework via energy efficiency has been a significant challenge for GCC nations. This study explores the leverage of energy efficiency and technology on CO2 emissions in the GCC region, with a time frame covering the period from 2008 to 2022. The study began by performing

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descriptive, correlational, and cross-sectional dependency tests. Consequently, assessing the stationarity of the variable series using first-generation panel unit root tests. The selected variables demonstrated mixed orders of integration. The panel co-integration tests were followed by the Panel ARDL test to inspect both short and long-run influences.

The finding shows that FTRI, energy intensity, and medium and high-tech manufacturing significantly increase CO_2 emissions among the GCC countries. Interestingly, agriculture and scientific and technical publications contribute to reducing CO2 emissions among the GCC countries. By utilizing global data and cutting-edge econometric approaches, this study aims to contribute to the expanding body of knowledge on how technology can drive sustainable environments and aid in the shift to a circular economy. The results are anticipated to have significant ramifications for decision-makers in government, business, and academia committed to building a more resilient and sustainable future. GCC countries are making significant efforts to mitigate climate change, including signing several climate agreements, such as the Paris Agreement. However, much work still needs to be done to meet global goals.

Policy Implications

The study's policy insights highlight a critical opportunity for the GCC countries to pivot toward sustainable growth by embracing eco-friendly technologies and energy efficiency policies. As high per capita energy consumers, the GCC nations, including Saudi Arabia, the UAE, Bahrain, Kuwait, Oman, and Qatar, face unique challenges in balancing economic growth with environmental sustainability. The current lack of robust energy efficiency policies means there is vast potential to reshape their energy consumption and emissions patterns, addressing both regional and global climate goals.

Existing Gaps and Emerging Initiatives in Energy Efficiency

The study underscores that most GCC countries have been slow to adopt comprehensive energy efficiency standards compared to global counterparts. While some efforts exist, they are generally limited in scope and application. Policymakers are increasingly aware of the need to reduce energy consumption. They are exploring measures such as: minimum energy efficiency standards, insulation requirements, energy labeling programs to inform consumers about the energy efficiency of products, encouraging market shifts toward greener options. Each of these initiatives not only contributes to reducing CO_2 emissions but also helps consumers and businesses lower costs, thereby building momentum for a green transition within the economy.

Saudi Arabia as a Model for Energy Reform in the GCC

Saudi Arabia's Vision 2030 and alignment with the SDGs reflect a commitment to both diversifying the economy and achieving sustainability. As the largest economy in the GCC and a prominent oil exporter, Saudi Arabia's actions set a significant precedent. Urban Planning and Infrastructure: With a growing population and rapid urbanization, Saudi Arabia recognizes the importance of sustainable infrastructure. New city projects, such as NEOM, are designed with a strong emphasis on environmental sustainability and energy efficiency, setting a model for eco-friendly urban planning.

Economic and Environmental Benefits of Adopting Eco-Friendly Technology

Eco-friendly technology aligns with the GCC's long-term economic goals by reducing dependence on oil exports and supporting new industries, such as clean energy production, green construction, and energy-efficient manufacturing. This shift can help mitigate the economic risks associated with fluctuating oil prices and global decarbonization trends. By adopting energy-efficient technologies, local industries can lower production costs, making GCC products more competitive on global markets. For example, reducing energy-intensive practices in sectors like aluminum production, petrochemicals, and cement can create cost savings, allowing these industries to compete more effectively internationally. The transition to a green economy can generate jobs in renewable energy, environmental management, technology development, and green infrastructure. These roles not only contribute to economic growth but also equip the workforce with

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future-oriented skills, enhancing regional resilience against economic disruptions. Lowering emissions improves air quality, which has direct health benefits by reducing respiratory diseases and associated healthcare costs. This can enhance the quality of life for citizens and reduce public healthcare expenditures, contributing to long-term economic stability.

Strategic Implications for the GCC's Global Position

If the GCC countries successfully implement eco-friendly policies and technologies, they could position themselves as leaders in sustainable development within the Middle East and North Africa (MENA) region. This leadership role could enhance their influence in international climate negotiations, allowing them to advocate for policies that consider the unique needs of oil-producing nations. By showcasing a commitment to sustainability, the GCC countries could attract foreign investment in renewable energy, sustainable agriculture, and environmentally conscious tourism. Such investments could diversify their economies and build a resilient financial ecosystem. The GCC countries have the potential to develop and export eco-friendly technologies, especially in areas like solar power, given the region's high levels of solar irradiance. By becoming innovators in green technology, they could create new revenue streams and foster partnerships with global clean-tech companies.

Challenges and Considerations in Policy Implementation

Many eco-friendly technologies and energy efficiency measures require high upfront investments. Policymakers need to weigh these costs against the long-term economic and environmental benefits. Financial incentives, such as subsidies for energy-efficient appliances or tax breaks for renewable energy investments, could support the adoption of green technologies. For policies like energy labeling or minimum efficiency standards to be effective, there needs to be a shift in consumer behavior. Public awareness campaigns could play a vital role in educating consumers on the benefits of energy efficiency and creating demand for eco-friendly products. Implementing energy-efficient practices and developing green technologies requires a skilled workforce. The GCC countries need to invest in education and training programs focused on renewable energy, environmental science, and sustainable engineering. Collaborations with universities and technical institutes can help build this expertise. As energy efficiency reduces domestic oil consumption, it could impact the revenue that GCC countries generate from oil sales. However, this challenge could be mitigated by exporting more oil or reinvesting oil revenues into the green transition, supporting new sectors while reducing dependence on fossil fuels.

Long-Term Impacts and Evolution of the Policy Landscape

Over time, increased adoption of eco-friendly technology could shift the GCC economies from oil-centric to diversified, knowledge-based economies. As eco-friendly policies reshape industries, they could reduce the carbon intensity of these economies, aligning them more closely with international climate goals. The GCC countries' efforts to reduce emissions and improve energy efficiency could have a substantial impact on global climate targets, especially if other oil-producing regions follow suit. This could also improve the GCC's reputation on the global stage, potentially attracting international partnerships in sustainable development. As technologies and policies evolve, GCC countries may continue to innovate in fields such as carbon capture, waste-to-energy, and hydrogen production. These advancements could not only reduce emissions but also provide new business opportunities in green technology.

The policy insights offered by the study reveal a transformative pathway for the GCC countries, where eco-friendly technology and energy efficiency can drive both economic growth and environmental sustainability. Although challenges exist, the alignment of these efforts with global sustainable development agendas provides a promising foundation for a green transition. By embracing these policies, the GCC countries can not only enhance their economic resilience but also contribute meaningfully to global climate action. The success of these efforts will hinge on the GCC's ability to maintain momentum, foster innovation, and adapt policies to meet evolving environmental and economic needs.

Future and research

This study encourages future research addressing the empirical evaluation of energy efficiency programs (such as smart grids, building codes, and industrial energy use) to determine their contribution to achieving national sustainability goals; Assessing the adoption of advanced technologies, particularly in sectors such as oil and gas, construction, and transportation, and their role in reducing environmental degradation; Comparative analysis of renewable energy initiatives, challenges in grid integration, and the role of international collaborations to drive renewable adoption in the region; Policy reforms, exploring the socioeconomic impacts of subsidy removal, and incentivizing the private sector to adopt green practices; Analyzing how renewable energy projects and energy-efficient technologies could align with the broader Vision 2030 initiatives in Saudi Arabia and similar strategies in other GCC states; and Examining how national policies align with international environmental agreements and the role of government institutions in facilitating sustainable transitions.

Data availability

The study employed open-access database in the analysis; it can be accessed via the following links:

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

https://unctadstat.unctad.org/datacentre

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Conflicts of Interest

The author declares no conflict of interest.

References

Khurshid, Nabila, Asma Fiaz, Kashif Ali, and Mudassar Rashid. "Unleashing the Effect of Energy Efficiency, Knowledge Spillover, and Globalization on Environmental Sustainability: An Vecm Analysis for Policy Empirics." Environment, Development and Sustainability 26, no. 3 (2024): 6027-49.

Song, Aifeng, Zeeshan Rasool, Raima Nazar, and Muhammad Khalid Anser. "Towards a Greener Future: How Green Technology Innovation and Energy Efficiency Are Transforming Sustainability." Energy 290 (2024): 129891.

Chen, Wei, Majed Alharthi, Jinjun Zhang, and Irfan Khan. "The Need for Energy Efficiency and Economic Prosperity in a Sustainable Environment." Gondwana Research 127 (2024): 22-35.

Wang, Rong, Muhammad Usman, Magdalena Radulescu, Javier Cifuentes-Faura, and Daniel Balsalobre-Lorente. "Achieving Ecological Sustainability through Technological Innovations, Financial Development, Foreign Direct Investment, and Energy Consumption in Developing European Countries." Gondwana Research 119 (2023): 138-52.

Dincer, Ibrahim, and Marc A Rosen. "Energy, Environment and Sustainable Development." Applied energy 64, no. 1-4 (1999): 427-40.

Ulussever, Talat, Mustafa Tevfik Kartal, and Ugur Korkut Pata. "Environmental Role of Technology, Income, Globalization, and Political Stability: Testing the Lcc Hypothesis for the Gcc Countries." Journal of Cleaner Production 451 (2024): 142056.

Sultan, Haider, Hafiz Ali Muhammad, Umair H Bhatti, Gwan Hong Min, Il Hyun Baek, Young-Jin Baik, and Sung Chan Nam. "Reducing the Efficiency Penalty of Carbon Dioxide Capture and Compression Process in a Natural Gas Combined Cycle Power Plant by Process Modification and Liquefied Natural Gas Cold Energy Integration." Energy Conversion and Management 244 (2021): 114495.

Karanfil, Fatih. "Energy Consumption and Economic Growth Revisited: Does the Size of Unrecorded Economy Matter?" Energy Policy 36, no. 8 (2008): 3029-35.

Khan, Muhammad Imran, Yusuf Bicer, Muhammad Asif, Tareq A Al-Ansari, Mushtaq Khan, Tonni A Kurniawan, and Sami G Al-Ghamdi. "The Gcc's Path to a Sustainable Future: Navigating the Barriers to the Adoption of Energy Efficiency Measures in the Built Environment." Energy Conversion and Management: X (2024): 100636.

Shaawat, M Essam, Rehan Jamil, and Mohammed M Al-Enezi. "Analysis of Challenges in Sustainable Construction Industry by Using Analytic Hierarchy Process: A Case Study of Jubail Industrial City, Saudi Arabia." International Journal of Sustainable Real Estate and Construction Economics 1, no. 2 (2018): 109-22.

Volume: 3, No: 7, pp. 2545 – 2565
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https://ecohumanism.co.uk/joe/ecohumanism
DOI: https://doi.org/10.62754/joe.v3i7.4399
Petratos, Pythagoras. "Sustainability and Financing Project: The Uae Paradigm." Paper presented at the Sustainable Development and Social Responsibility—Volume 1: Proceedings of the 2nd American University in the Emirates International Research Conference, AUEIRC'18–Dubai, UAE 2018 2020.
Saleh, Redhwan Mohammed, and Abdullah Al-Swidi. "The Adoption of Green Building Practices in Construction Projects in Qatar: A Preliminary Study." Management of Environmental Quality: An International Journal 30, no. 6 (2019): 1238-55.
Marzooq, Hassan, Humood A Naser, and EM Elkanzi. "Quantifying Exposure Levels of Coastal Facilities to Oil Spills in Bahrain, Arabian Gulf." Environmental monitoring and assessment 191 (2019): 1-16.
Uddin, Saif, Scott W Fowler, Talat Saeed, Barry Jupp, and Mohd Faizuddin. "Petroleum Hydrocarbon Pollution in Sediments from the Gulf and Omani Waters: Status and Review." Marine Pollution Bulletin 173 (2021): 112913.
Alam, Meredian, and Izni Azrein Noor Azalie. "Greening the Desert: Sustainability Challenges and Environmental Initiatives in the Gcc States." In Social Change in the Gulf Region: Multidisciplinary Perspectives, 493-510: Springer Nature Singapore Singapore, 2023.
Almasri, Radwan A, and S Narayan. "A Recent Review of Energy Efficiency and Renewable Energy in the Gulf Cooperation Council (Gcc) Region." International Journal of Green Energy 18, no. 14 (2021): 1441-68.
Fattouh, Bassam, Anupama Sen, and Tom Moerenhout. "Striking the Right Balance? Gcc Energy Pricing Reforms in a Low Price Environment." Oxford Institute for Energy Studies, Oxford (2016).
Nematollahi, Omid, Hadi Hoghooghi, Mehdi Rasti, and Ahmad Sedaghat. "Energy Demands and Renewable Energy Resources in the Middle East." Renewable and Sustainable Energy Reviews 54 (2016): 1172-81.
Nikbakht, Mohamad, Parviz Hajiani, and Ahmad Ghorbanpur. "Assessment of the Total-Factor Energy Efficiency and Environmental Performance of Persian Gulf Countries: A Two-Stage Analytical Approach." Environmental science and pollution research 30, no. 4 (2023): 10560-98.
Qader, Mohammed Redha. "Electricity Consumption and Ghg Emissions in Gcc Countries." Energies 2, no. 4 (2009): 1201-13.
Al-shammari, Awwad Saad Awwad, Saqib Muneer, and Abhishek Tripathi. "Do Information Communication Technology and Economic Development Impact Environmental Degradation? Evidence from the Gcc Countries." Frontiers in Environmental Science 10 (2022): 875932.
Oyewole, Oluwatomisin J, Mamdouh Abdulaziz Saleh Al-Faryan, Oluwasegun B Adekoya, and Johnson A Oliyide. "Energy Efficiency, Financial Inclusion, and Socio-Economic Outcomes: Evidence across Advanced, Emerging, and Developing Countries." Energy 289 (2024): 130062.
Cantore, Nicola, Massimiliano Calì, and Dirk Willem te Velde. "Does Energy Efficiency Improve Technological Change and Economic Growth in Developing Countries?" Energy Policy 92 (2016): 279-85.
Rasoulinezhad, Ehsan, and Farhad Taghizadeh-Hesary. "Role of Green Finance in Improving Energy Efficiency and Renewable Energy Development." Energy Efficiency 15, no. 2 (2022): 14.
Tan, Duojiao, Bushra Komal, Ernest Ezeani, Muhammad Usman, and Rami Salem. "Carbon Emission Disclosures and Financial Reporting Quality: Does Ownership Structure and Economic Development Matter?" Environmental Science & Policy 137 (2022): 109-19.
Sarabdeen, Masahina, Manal Elhaj, and Hind Alofaysan. "Exploring the Influence of Digital Transformation on Clean Energy Transition, Climate Change, and Economic Growth among Selected Oil-Export Countries through the Panel Ardl Approach." Energies 17, no. 2 (2024): 298.
Milindi, Chris Belmert, and Roula Inglesi-Lotz. "Impact of Technological Progress on Carbon Emissions in Different Country Income Groups." Energy & Environment 34, no. 5 (2023): 1348-82.
Delanoë, Paul, Dieudonné Tchuente, and Guillaume Colin. "Method and Evaluations of the Effective Gain of Artificial Intelligence Models for Reducing Co2 Emissions." Journal of environmental management 331 (2023): 117261.
Yan, Yuan, Khatib Ahmad Khan, Tomiwa Sunday Adebayo, and Victoria Olushola Olanrewaju. "Unveiling Energy Efficiency and Renewable Electricity's Role in Achieving Sustainable Development Goals 7 and 13 Policies." International Journal of Sustainable Development & World Ecology (2024): 1-26.
Dzwigol, Henryk, Aleksy Kwilinski, Oleksii Lyulyov, and Tetyana Pimonenko. "The Role of Environmental Regulations, Renewable Energy, and Energy Efficiency in Finding the Path to Green Economic Growth." Energies 16, no. 7 (2023): 3090.
Alam, Md Shabbir, Mohammad Noor Alam, Muntasir Murshed, Haider Mahmood, and Risana Alam. "Pathways to Securing Environmentally Sustainable Economic Growth through Efficient Use of Energy: A Bootstrapped Ardl Analysis." Environmental science and pollution research 29, no. 33 (2022): 50025-39.
Adebayo, Tomiwa Sunday, and Sami Ullah. "Towards a Sustainable Future: The Role of Energy Efficiency, Renewable Energy, and Urbanization in Limiting Co2 Emissions in Sweden." Sustainable Development 32, no. 1 (2024): 244-59.
Wenlong, Zheng, Nguyen Hoang Tien, Amena Sibghatullah, Daru Asih, Mochamad Soelton, and Yanto Ramli. "Impact of Energy Efficiency, Technology Innovation, Institutional Quality, and Trade Openness on Greenhouse Gas Emissions in Ten Asian Economies." Environmental science and pollution research 30, no. 15 (2023): 43024-39.
Jin, Xin, Zahoor Ahmed, Ugur Korkut Pata, Mustafa Tevfik Kartal, and Sinan Erdogan. "Do Investments in Green Energy, Energy Efficiency, and Nuclear Energy R&D Improve the Load Capacity Factor? An Augmented Ardl Approach." Geoscience Frontiers 15, no. 4 (2024): 101646.
Liu, Xuan, Tomiwa Sunday Adebayo, Muhammad Ramzan, Sami Ullah, Shujaat Abbas, and Victoria Olushola Olanrewaju. "Do Coal Efficiency, Climate Policy Uncertainty and Green Energy Consumption Promote Environmental Sustainability in the United States? An Application of Novel Wavelet Tools." Journal of Cleaner Production 417 (2023): 137851.

Journal of Ecohumanism
2024
Volume: 3, No: 7, pp. 2545 – 2565
ISSN: 2752-6798 (Print) | ISSN 2752-6801 (Online)
https://ecohumanism.co.uk/joe/ecohumanism
DOI: https://doi.org/10.62754/joe.v3i7.4399
Zhang, Lu, Renyan Mu, Yuanfang Zhan, Jiahong Yu, Liyi Liu, Yongsheng Yu, and Jixin Zhang. "Digital Economy, Energy Efficiency, and Carbon Emissions: Evidence from Provincial Panel Data in China." Science of the Total Environment 852 (2022): 158403.
Sultana, Munira, and Md Hasanur Rahman. "Investigating the Impact of Gdp, Energy Mix, Energy Intensity, and the Service Sector on Environmental Pollution in Mena Countries: An Application of Driscoll-Kraay Standard Error Approach." Social Sciences & Humanities Open 10 (2024): 101087.
Singh, Amit Kumar, Syed Ali Raza, Joanna Nakonieczny, and Umer Shahzad. "Role of Financial Inclusion, Green Innovation, and Energy Efficiency for Environmental Performance? Evidence from Developed and Emerging Economies in the Lens of Sustainable Development." Structural Change and Economic Dynamics 64 (2023): 213-24.
Zakari, Abdulrasheed, Irfan Khan, Duojiao Tan, Rafael Alvarado, and Vishal Dagar. "Energy Efficiency and Sustainable Development Goals (Sdgs)." Energy 239 (2022): 122365.
Rehman Khan, Syed Abdul, Zhang Yu, Ibrahim Lanre Ridwan, Rehman Irshad, Pablo Ponce, and Muhammad Tanveer. "Energy Efficiency, Carbon Neutrality and Technological Innovation: A Strategic Move Towards Green Economy." Economic research-Ekonomska istraživanja 36, no. 2 (2023).
Su, Chi Wei, Fangying Liu, Petru Stefea, and Muhammad Umar. "Does Technology Innovation Help to Achieve Carbon Neutrality?" Economic Analysis and Policy 78 (2023): 1-14.
Radulescu, Magdalena, Javier Cifuentes-Faura, Kamel Si Mohammed, and Hind Alofaysan. "Energy Efficiency and Environmental Regulations for Mitigating Carbon Emissions in Chinese Provinces." Energy Efficiency 17, no. 6 (2024): 67.
Adebayo, Tomiwa Sunday, Oktay Özkan, and Babatunde Sunday Eweade. "Do Energy Efficiency R&D Investments and Information and Communication Technologies Promote Environmental Sustainability in Sweden? A Quantile-on-Quantile Krls Investigation." Journal of Cleaner Production 440 (2024): 140832.
Chien, Fengsheng, Tahseen Ajaz, Zubaria Andlib, Ka Yin Chau, Paiman Ahmad, and Arshian Sharif. "The Role of Technology Innovation, Renewable Energy and Globalization in Reducing Environmental Degradation in Pakistan: A Step Towards Sustainable Environment." Renewable Energy 177 (2021): 308-17.
Aneja, Ranjan, Manisha Yadav, and Sanjeev Gupta. "The Dynamic Impact Assessment of Clean Energy and Green Innovation in Realizing Environmental Sustainability of G-20." Sustainable Development 32, no. 3 (2024): 2454-73.
Sarabdeen, Masahina, Manal Elhaj, and Hind Alofaysan. "Do Digital Adaptation, Energy Transition, Export Diversification, and Income Inequality Accelerate Towards Load Capacity Factors across the Globe?" Energies 17, no. 16 (2024): 3981.
Alofaysan, Hind. "The Effect of Environmental Smart Technology and Renewable Energy on Carbon Footprint: A Sustainability Perspective from the Mena Region." Energies 17, no. 11 (2024): 2624.
Elmonshid, Lena Bedawi Elfadli, Omer Ahmed Sayed, Ghadda Mohamed Awad Yousif, Kamal Eldin Hassan Ibrahim Eldaw, and Muawya Ahmed Hussein. "The Impact of Financial Efficiency and Renewable Energy Consumption on Co2 Emission Reduction in Gcc Economies: A Panel Data Quantile Regression Approach." Sustainability 16, no. 14 (2024): 6242.
Petković, Biljana, Yousef Zandi, Alireza Sadighi Agdas, Ivica Nikolić, Nebojša Denić, Nenad Kojić, Abdellatif Selmi, Alibek Issakhov, Slaviša Milošević, and Afrasyab Khan. "Adaptive Neuro Fuzzy Evaluation of Energy and Non-Energy Material Productivity Impact on Sustainable Development Based on Circular Economy and Gross Domestic Product." Business Strategy and the Environment 31, no. 1 (2022): 129-44.
Fernández, Y Fernández, MA Fernández López, and B Olmedillas Blanco. "Innovation for Sustainability: The Impact of R&D Spending on Co2 Emissions." Journal of Cleaner Production 172 (2018): 3459-67.
Churchill, Sefa Awaworyi, John Inekwe, Kris Ivanovski, and Russell Smyth. "The Environmental Kuznets Curve in the Oecd: 1870–2014." Energy economics 75 (2018): 389-99.
Aziz, Ghazala, Suleman Sarwar, Rida Waheed, and Mohd Saeed Khan. "The Significance of Renewable Energy, Globalization, and Agriculture on Sustainable Economic Growth and Green Environment: Metaphorically, a Two-Sided Blade." Paper presented at the Natural resources forum 2024.
Asumadu-Sarkodie, Samuel, and Phebe Asantewaa Owusu. "The Impact of Energy, Agriculture, Macroeconomic and Human-Induced Indicators on Environmental Pollution: Evidence from Ghana." Environmental science and pollution research 24, no. 7 (2017): 6622-33.
Adedoyin, Festus Fatai, Andrew Adewale Alola, and Festus Victor Bekun. "The Nexus of Environmental Sustainability and Agro-Economic Performance of Sub-Saharan African Countries." Heliyon 6, no. 9 (2020).
Zeng, Queling, Mehmet Akif Destek, Zeeshan Khan, Ramez Abubakr Badeeb, and Changyong Zhang. "Green Innovation, Foreign Investment and Carbon Emissions: A Roadmap to Sustainable Development Via Green Energy and Energy Efficiency for Brics Economies." International Journal of Sustainable Development & World Ecology 31, no. 2 (2024): 191-205.
Alfantookh, Nasreen, Yousif Osman, and Isam Ellaythey. "Implications of Transition Towards Manufacturing on the Environment: Saudi Arabia's Vision 2030 Context." Journal of Risk and Financial Management 16, no. 1 (2023): 44.
Ghosh, Sudeshna, Tomiwa Sunday Adebayo, Shujaat Abbas, Buhari Doğan, and Samuel Asumadu Sarkodie. "Harnessing the Roles of Renewable Energy, High Tech Industries, and Financial Globalization for Environmental Sustainability: Evidence from Newly Industrialized Economies." Paper presented at the Natural Resources Forum 2023.
Burmaoglu, Serhat, Dilek Ozdemir Gungor, Aynur Kirbac, and Ozcan Saritas. "Future Research Avenues at the Nexus of Circular Economy and Digitalization." International Journal of Productivity and Performance Management 72, no. 8 (2023): 2247-69.
Pesaran, M Hashem, Yongcheol Shin, and Ron P Smith. "Pooled Mean Group Estimation of Dynamic Heterogeneous Panels." Journal of the American statistical Association 94, no. 446 (1999): 621-34.

Journal of Ecohumanism
2024
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https://ecohumanism.co.uk/joe/ecohumanism
DOI: https://doi.org/10.62754/joe.v3i7.4399
Pesaran, M Hashem, and Ron Smith. "The Role of Theory in Econometrics." Journal of econometrics 67, no. 1 (1995): 61-79.
Pesaran, M Hashem. "General Diagnostic Tests for Cross-Sectional Dependence in Panels." Empirical economics 60, no. 1 (2021): 13-50.
Pesaran, M Hashem, Aman Ullah, and Takashi Yamagata. "A Bias-Adjusted Lm Test of Error Cross-Section Independence." The econometrics journal 11, no. 1 (2008): 105-27.
Breusch, Trevor S, and Adrian R Pagan. "The Lagrange Multiplier Test and Its Applications to Model Specification in Econometrics." The review of economic studies 47, no. 1 (1980): 239-53.
Pesaran, M Hashem. "General Diagnostic Tests for Cross Section Dependence in Panels. Cambridge Working Papers." Economics 1240, no. 1 (2004): 1.
———. "A Simple Panel Unit Root Test in the Presence of Cross-Section Dependence." Journal of applied econometrics 22, no. 2 (2007): 265-312.
Pedroni, Peter. "Critical Values for Cointegration Tests in Heterogeneous Panels with Multiple Regressors." Oxford Bulletin of Economics and statistics 61, no. S1 (1999): 653-70.
Wang, Juan, Sulan Zhang, and Qingjun Zhang. "The Relationship of Renewable Energy Consumption to Financial Development and Economic Growth in China." Renewable Energy 170 (2021): 897-904.
Pesaran, M Hashem, Yongcheol Shin, and Richard J Smith. "Bounds Testing Approaches to the Analysis of Level Relationships." Journal of applied econometrics 16, no. 3 (2001): 289-326.
Dumitrescu, Elena-Ivona, and Christophe Hurlin. "Testing for Granger Non-Causality in Heterogeneous Panels." Economic modelling 29, no. 4 (2012): 1450-60.
Levin, Andrew, Chien-Fu Lin, and Chia-Shang James Chu. "Unit Root Tests in Panel Data: Asymptotic and Finite-Sample Properties." Journal of econometrics 108, no. 1 (2002): 1-24.
Kao, Chihwa. "Spurious Regression and Residual-Based Tests for Cointegration in Panel Data." Journal of econometrics 90, no. 1 (1999): 1-44.
Raihan, Asif, Shewly Bala, Afsana Akther, Mohammad Ridwan, Md Eleais, and Prattoy Chakma. "Advancing Environmental Sustainability in the G-7: The Impact of the Digital Economy, Technological Innovation, and Financial Accessibility Using Panel Ardl Approach." Journal of Economy and Technology (2024).
Bose, Bimal K. "Global Warming: Energy, Environmental Pollution, and the Impact of Power Electronics." IEEE Industrial Electronics Magazine 4, no. 1 (2010): 6-17.
Al-Ghussain, Loiy. "Global Warming: Review on Driving Forces and Mitigation." Environmental Progress & Sustainable Energy 38, no. 1 (2019): 13-21.
Yoro, Kelvin O, and Michael O Daramola. "Co2 Emission Sources, Greenhouse Gases, and the Global Warming Effect." In Advances in Carbon Capture, 3-28: Elsevier, 2020.