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Research Article

A Dynamic Interrelationships among Clean Energy, Environmental Pollution, and Economic Growth in GCC Economies: A Panel ARDL Approach

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The paper investigates the interplay between clean energy, environmental pollution reduction, and economic growth in the Gulf Cooperation Council (GCC) countries from 1980 to 2019, utilizing the autoregressive distributed lag (ARDL) method. The study underscores the global transition towards cleaner energy sources and its implications for the region. In assessing the determinants of economic growth, the findings reveal a positive and significant short- and long-term impact of energy production, with energy consumption exhibiting a positive and significant effect solely in the long term. The absence of a confirmed relationship in the short term is notable. Causality tests demonstrate a significant link from both energy consumption types to environmental pollution, alongside causal relationships from urbanization, energy production, and consumption to economic growth. Moreover, the results include the pivotal role of energy production in driving GDP growth, caution in short-term energy consumption effects, and significant causal links between energy consumption and environmental pollution. The recommendations to incentivize sustainable energy production, engage in long-term energy consumption planning, and adopt integrated urbanization policies provide actionable insights for policymakers. These suggestions are aimed at guiding the GCC countries in balancing the pursuit of economic growth with environmental sustainability—a delicate equilibrium that necessitates careful consideration of various factors.

1. Introduction

The nexus between economic growth, environmental pollution, and energy has been assessed excessively by academics over the past few decades. Amid global discussions on climate change, the relationship between economic prosperity and environmental degradation has emerged as a critical focal point. Notably, Simon Kuznets, a laureate of the 1971 Nobel Prize, introduced the concept of an inverted-U relationship between per capita income and income inequality, positing that as income rises, so does inequality until a tipping point, after which inequality diminishes. This notion has been extended to the environmental domain, leading to the formulation and testing of the environmental Kuznets curve (EKC) by researchers such as Grossman and Krueger [1] and Panayotou [2]. Integral to contemporary societies, energy serves as the lifeblood of economic growth and individual well-being. However, the dual role of energy as a catalyst for industrial progress and a source of environmental pollutants, particularly from fossil fuels, underscores a complex conundrum. For the Gulf Cooperation Council (GCC) countries, whose economies heavily rely on fossil fuels, this challenge is particularly pronounced, with a substantial portion of government income derived from natural resources [3–5]. Diverging from conventional research approaches, this study, influenced by Rahman et al. [6], uniquely considers both energy production and consumption. Recognizing the nuanced impact of energy production on the environment and gross domestic product, we scrutinize the specific contributions of natural gas and oil-based energy production. This distinction becomes paramount as we direct our focus towards understanding the implications for clean energy production, contributing valuable insights for the formulation of economic policies that foster sustainable development [7, 8]. The trinity of economic growth, environment, and energy forms the crux of our investigation, portrayed as an inverted-U curve. As per this model, environmental pollution escalates alongside increasing per capita income until a critical juncture, beyond which pollution abates while income continues to rise. This conceptual framework lays the foundation for our exploration of the transformative potential of clean energy on economic growth. While the nexus between clean energy and economic growth has been a subject of considerable scholarly attention, our study aligns with the prevailing global trend towards adopting environmentally friendly energy sources. Clean energy emerges not merely as a response to environmental concerns but as a pivotal driver of economic progress, influencing production, transportation, and manufacturing processes [9, 10]. Recognizing the substantial capital costs and ongoing maintenance associated with clean energy, our research posits that such investments stimulate economic growth by creating job opportunities in various sectors. Beyond economic advantages, the adoption of clean energy contributes to energy security and mitigates greenhouse gas emissions, emblematic of a commitment to sustainable economic growth. In essence, our study underscores the transformative potential of clean energy adoption, advocating for its role as a linchpin in achieving economic prosperity while upholding environmental sustainability. As we delve into the intricate interplay between economic growth, environmental dynamics, and energy in the Gulf Cooperation Council (GCC) countries, the purpose of our study unfolds with a dual objective. Firstly, we aim to unravel the unique dynamics and challenges faced by these fossil fuel-based economies, providing insights that transcend the conventional discourse on the subject. The choice of GCC countries as our focal point stems from their pivotal role in global energy markets and the pressing need to understand how their economic growth aligns with environmental sustainability. Secondly, the Gulf Cooperation Council (GCC) region boasts the world's most extensive energy reserves. However, as the region endeavors to industrialize and modernize its economies, it grapples with the dual challenges of greenhouse gas (GHG) emissions. Notably, energy consumption emerges as the primary contributor to environmental pollution in these ambitious pursuits. Also, the choice of the study period from 1980 to 2019 allows for a more in-depth analysis of the prepandemic era and ensures a robust foundation for understanding long-term patterns. Extending the study period or expanding the geographical scope could be considered for future research to provide a comprehensive view of the subject. As we embark on this exploration of the nexus between economic growth, environmental dynamics, and energy in the GCC countries, it is essential to acknowledge the temporal context within which our analysis unfolds. The decision to focus on the prepandemic era aligns with the aim of capturing the dynamics preceding the global disruptions of recent times. By delving into the intricacies of the period up to 2019, we aim to establish a solid baseline for comprehending the long-term implications and trends in our study. The nuanced understanding gained from this focused examination will not only contribute to the ongoing discourse on sustainable development but also pave the way for future research endeavors. Considering the evolving nature of the subject, our deliberate choice of timeframe positions our study as a valuable reference point, laying the groundwork for potential expansions in both temporal and geographical dimensions in subsequent investigations. To navigate the complexity of this relationship, we employ the panel autoregressive distributed lag (panel ARDL) methodology, a deliberate choice over the commonly used quasi autoregressive distributed lag (QARDL) approach. The decision to opt for panel ARDL is grounded in its ability to capture both short- and long-term dynamics in a panel data setting, offering a more comprehensive understanding of the relationships under scrutiny. This methodological choice enhances the robustness of our analysis, allowing for nuanced insights into the evolving patterns over time. Furthermore, our study adopts specific models in estimations to refine our understanding of the intricate connections between economic growth, environmental factors, and energy production. By employing two primary models, one focusing on pollution and the other on economic growth (each of these overarching models comprises six submodels), we aim to discern the nuanced impact of clean energy adoption on economic growth, providing policymakers with valuable information for informed decision-making. As we navigate through the subsequent sections of this paper, the confluence of purpose, methodology, and analytical approach will unfold, shedding light on the multifaceted relationships that underpin sustainable economic development in the GCC countries. In addition, the remaining sections of the paper are organized as follows: Section 2 provides a concise overview of the theoretical background and existing empirical studies. In Section 3, we delve into the modeling framework and present the estimation results. The concluding section summarizes the study and explores its policy implications.

2. Literature Review

There are three types of research in the topic of the relationship between economic growth, environmental pollution, and energy consumption [11–15]. They are divided based on the relationship they are focused on. Economic growth, environment, and energy are the poles of the studies. They are vital for any economy in the world, so academic scientists and policymakers are involved in them. The first one focus on the relationship between economic growth and environment such as Apergis and Ozturk [16], Fodha and Zaghdoud [17], P. Narayan and S. Narayan [18], and Omri et al. [19] (see Table 1). They are closely testing the validity of EKC hypothesis. Most of these research confirmed the EKC hypotheses while others do not such as Ozturk and Al-Mulali [20]. However, geographic areas differ from one study to others as well as period, econometric techniques, and variables. Omri et al. [21] confirmed the existence of EKC in Saudi Arabia for the period of 1980–2014. The

Table 1: Economic growth and environment.

Author	Period	Country	Variables	Method	Results
Apergis and Ozturk [16]	1990–2011	14 Asian countries	CO_2, population, GDP, land, share	Panel cointegration, FMOLS, DOLS, PMGE, MG	Yes EKC
Fodha and Zaghdoud [17]	1961-2004	Tunisia	CO_2, SO_2, GDP	Time series cointegration	Yes: SO_2 No: CO_2
P. Narayan and S. Narayan [18]	1980-2004	43 developing countries	CO_2, GDP	Panel cointegration	Yes EKC
Omri et al. [19]	1990–2011	54 countries	CO_2, FDI, GDP	Dynamic simultaneous-equation panel data	Yes EKC
Omri et al. [21]	1990-2014	Saudi	GDP, FD, HC, FDI, OP, CO_2	DOLS, FMOLS	Yes EKC
Saboori et al. [32]	1980-2009	Malaysia	CO_2, GDP	ARDL cointegration	Yes EKC
Ulucak and Bilgili [33]	1961-2013	3 income groups	EF, GDP, HC, OP, BC	CUP-FM, CUP-BC	Yes EKC
Wang [34]	1971-2007	98 countries	CO_2, GDP	Panel cointegration, FMOLS	Yes EKC

Note. The table defined selected references which presented studies about economic growth and environment (created by the author).

second type of research focuses on the relationship between energy economic growth and energy (see Table 2). The result of this type of research classifies economies into four hypothesis [22]. Conservation hypothesis assumes that there is a unidirectional causality from economic growth to energy consumption and less energy-dependent economies such Sri Lanka in Zahid's [23] study. Growth hypothesis assumes that there is a unidirectional causality from energy consumption to economic growth and energy-dependent economies such as Hasan and Raza [24]. Feedback hypothesis assumes that there is a bidirectional causality between energy consumption and economic growth such as Hamdi et al. [25], Heidari et al. [26], Solarin and Ozturk [27], and Alam et al. [12–14]. Lastly, neutrality hypothesis assumes no causality relationship between energy consumption and economic growth; in these economies, expensive energy policies could be easily implemented such as Saudi Arabia and Kuwait in Ozturk and Al-Mulali's [28] study. Finally, most of these studies are using energy consumption, but Rahman et al. [6] used both energy consumption and energy production. The third type of research combines those two types of research in the topic which investigates the relationship between economic growth, environmental pollution, and energy consumption (see Table 3). Studies use different variables and techniques for many different geographic areas to find the answer of how economic growth is affected by environment and energy and vice versa. For example, Salahuddin and Gow [29] and Salahuddin et al. [30] study the relationship in GCC area by using GDP, CO_2, and energy consumption or electric consumption while Mrabet and Alsamara [31] study individual country which is Qatar. In this study, we used energy production instead of energy consumption that was used for many study. Energy production is crucial for any economy because energy is fuel for industry as well as any economic sector. The tables below present many informative studies which help to understand the different roles of clean energy and environmental pollution on economic growth in many countries around the world that give more explanation to the research model.

Al-Mawali et al. [60], Al-Sarihi [61], and Hamid et al. [60] argued that Gulf Cooperation Council (GCC) is an alliance of six Middle Eastern countries, including Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates. These countries are known for their vast reserves of oil and natural gas, which have been the backbone of their economies for decades. However, as the world faces the challenges of climate change and environmental degradation, the GCC economies are increasingly recognizing the importance of transitioning towards clean energy sources to mitigate pollution and promote sustainable economic growth.

2.1. Clean Energy in GCC Economies. Clean energy refers to renewable energy sources that have a minimal impact on the environment and do not deplete natural resources. The GCC countries are endowed with abundant solar and wind resources, making them suitable for the development of clean energy projects. In recent years, there has been a growing interest in harnessing these renewable resources to diversify the energy mix and reduce dependency on fossil fuels [12–14, 63–65].

(a) Solar energy: the GCC region receives high levels of solar irradiation, making solar power a promising renewable energy source. Countries like the UAE and Saudi Arabia have been investing heavily in large-scale solar projects, such as solar parks and rooftop installations, to generate electricity

(b) Wind energy: while the GCC countries have less consistent wind resources compared to solar, some areas have suitable wind conditions for wind power projects. Oman, for example, has been exploring wind farms to complement its energy mix

(c) Nuclear energy: In addition to solar and wind, some GCC countries have been considering nuclear power as a low-carbon energy source. The UAE, for instance, has launched the Barakah nuclear power plant project to diversify its energy portfolio

TABLE 2: Economic growth and energy.

Author	Period	Country	Variables	Method	Results
Hamdi et al. [25]	1980-2010	Bahrain	FDI, GDP, electric, K	ARDL	Electric ↔ GDP
Hasan and Raza [24]	1990–2019	Bangladesh	NG, GDP	ARDL	NG → GDP
Heidari et al. [26]	1972–2007	Iran	NG, GDP, capital, labor	MPM	NG ↔ GDP
Kesikoglu and Yıldırım [35]	1980–2012	OECD countries	NG, GDP	SUR, OLS	NG → GDP
Ozturk and Al-Mulali [28]	1980-2012	GCC	Fossil fuels, electricity, GDP, K, L, X, M	ARDL, TYDL	UAE and Bahrain: fossil electr. ↔ GDP Qatar and Oman: fossil electr. → GDP Saudi and Kuwait: no causality
Ozturk and Al-Mulali [20]	1980–2012	GCC countries	NG, GDP, OP, L, K	DOLS-FMOLS	NG ↔ GDP
Solarin and Ozturk [27]	1980–2012	12 OPEC countries	NG, GDP	PGC	NG ↔Y
Zahid [23]	1971-2003	5 Asian Countries	NG, GDP, petroleum, coal, electricity, EC	VECM, TYDL	India: no causality Sri Lanka: GDP → electricity cons. and EC Bangladesh: GDP → electr. and NG → GDP Nepal: petroleum → GDP
Rahman et al. [6]	1981-2016	China	Energy production, EC, and GDP	FMOLS, CCR, VECM	Production coal, oil, and gas → GDP

Note. The table defined selected references which presented studies about economic growth and energy (created by the author).

2.2. Environmental Pollution in GCC Economies. Despite their abundant fossil fuel resources, GCC countries have been grappling with severe environmental challenges, primarily related to pollution. The extraction, processing, and combustion of oil and gas have significant environmental consequences, such as air and water pollution and greenhouse gas emissions [5, 8, 66].

(a) Air pollution: industrial activities and high levels of vehicle usage contribute to air pollution in major cities of the GCC. Particulate matter, nitrogen oxides (NOx), and volatile organic compounds (VOCs) are among the pollutants that have adverse effects on human health and the environment

(b) Water pollution: the oil and gas industry, as well as rapid urbanization and industrialization, have resulted in water pollution, particularly in coastal areas. Oil spills and untreated sewage can degrade marine ecosystems and threaten biodiversity

(c) Greenhouse gas emissions: GCC economies are significant contributors to global greenhouse gas emissions due to their heavy reliance on fossil fuels. These emissions contribute to climate change, leading to rising sea levels, extreme weather events, and other environmental disruptions

2.3. Economic Growth in GCC Region. Historically, the economies of GCC countries have been heavily reliant on oil and gas exports, with hydrocarbons contributing significantly to their GDPs. While this reliance has brought substantial wealth, it has also made these economies vulnerable to fluctuations in global oil prices [12–14, 67, 68].

(a) Diversification: in response to the volatility of oil markets and the need for sustainable economic growth, GCC countries have been actively working towards economic diversification. They aim to reduce their dependence on oil revenues by investing in sectors such as tourism, technology, manufacturing, and renewable energy

(b) Job creation: economic diversification and investment in clean energy can lead to job creation and provide opportunities for skilled and educated youth in nonoil sectors. This, in turn, can reduce unemployment rates and enhance the overall economic stability of the region

(c) Energy security: investing in clean energy can enhance the energy security of GCC countries by reducing their reliance on imported fossil fuels. By harnessing their renewable energy potential, they can ensure a more stable and sustainable energy supply for their economies

In the intricate dance of globalization, renewable energy, and agriculture, the primary concern lies in their collective impact on sustainability, economic growth, and environmental security. Globalization, while fostering economic interdependence, can also lead to a race to the bottom in environmental standards, unless robust international agreements and institutions are in place to ensure responsible practices. The transition to renewable energy sources holds immense promise for reducing carbon emissions, but the economic challenges of phasing out fossil fuels and the need for a just transition for affected communities must be carefully addressed. Agriculture, a cornerstone of human survival, is

Table 3: Economic growth, environment, and energy.

Author	Period	Country	Variables	Method	Results
Acar and Astcu [36]	2006	105 countries	EF, GDP, BC, OP, population, industry share, EC, envir. regulations	Cross-section analysis	Yes EKC
Acar et al. [36]	2004-2008	116 countries	EF, BC, GDP, OP, population, industry, EC, stringency, enforcement	Panel FE	Yes EKC
Ali et al. [37]	1996-2017	33 European countries	CO_2, GDP, renewable energy, EC, urbanization, imports, exports	FMOLS	Yes EKC
Alkhathlan and Javid [38]	1980-2011	Saudi	GDP, CO_2, EC	ARDL	GDP → CO_2
Arouri et al. [39]	1981-2005	12 MENA countries	GDP, CO_2, EC	Panel cointegration	No EKC
Asongu et al. [40]	1982-2011	24 African	EC, CO_2, GDP	Panel ARDL	CO_2, EC → GDP
Bechir Raggad [41]	1971–2014	Saudi	CO_2, GDP, EC, urbanization	ARDL	No EKC
Beşe, Kalayci [42]	1960-2014	3 developed	GDP, CO_2, EC	ARDL, TYDL	Neutrality hypothesis
Bilgili et al. [43]	1977-2010	17 OECD countries	GDP, CO_2, renewable energy	Panel FMOLS, panel DOLS	Yes EKC
Charfeddine and Mrabet [44]	1995-2007	MENA 15	EF, GDP, EC, urbanization, fertility, life expectancy	Panel FMOLS, panel DOLS	Yes EKC
Danish et al. [45]	1970-2011	Pakistan	Energy production, GDP, CO_2	Johansen cointegration	Yes EKC, energy production → CO_2
Destek and Sarkodie [46]	1977-2013	11 newly industrialized countries	EF, GDP, EC, FD	AMG	Yes EKC
Dogan and Turkekul [47]	1960-2010	USA	CO_2, EC, GDP, GDP2, OP, FD, urbanization	ARDL	No EKC
Gorus and Aslan [48]	1980-2013	MENA	CO_2, GDP, FDI, EC	Panel cointegration	EC → CO_2
Gorus, Aydin [22]	1975-2014	NENA	EC, GDP, CO_2	Multicountry Granger causality	GDP → EC
Hamit-Haggar [49]	1990–2007	Canada	EC, GDP, greenhouse gas emissions	Panel data framework	Yes EKC, EC → greenhouse gas emissions
Mrabet and Alsamara [31]	1980-2011	Qatar	EF, CO_2 energy use, financial development, openness	ARDL	Yes EKC
Nasir and Ur Rehman [50]	1972–2008	Pakistan	CO_2, GDP, EC	Time series cointegration	GDP → EC
Omri [19]	1990-2011	14 MENA	CO_2, EC, GDP	Cobb–Douglas production function	GDP ↔ CO_2
Ozcan [51]	1990-2008	Middle East	CO_2, GDP, EC	Panel cointegration, FMOLS, VECM	Yes, EKC in 5 Middle East countries
Ozcan et al. [52]	2000-2014	OECD	EF, EC, GDP, CO_2	GMM-PVAR	GDP ↔ EC
Ozturk and Acaravci [53]	1960-2007	Turkey	CO_2, EC, GDP, FDI, FD	ARDL	Yes EKC
Ozturk et al. [54]	1988-2008	144 countries	EF, GDP of tourism, OP, urban population, EC	Time series GMM, S-GMM	No EKC for low and lower-middle income Yes EKC for upper-middle and high income
Ozturk and Acaravci [11]	1968-2005	Turkey	GDP, CO_2, EC	ARDL	No EKC

Table 3: Continued.

Author	Period	Country	Variables	Method	Results
Ozturk and Al-Mulali [20]	1996–2012	Cambodia	Electric, GDP, CO_2, corruption, governance, urbanization	GMM, 2SLS	No EKC
Saboori [55]	1960-2008	OECD	GDP, CO_2, transportation energy consumption	FMOLS	EC ↔ CO_2
Salahuddin et al. [30]	1980-2012	GCC	Electric, GDP, CO_2, FD	FMOLS	Electric and GDP → CO_2
Salahuddin and Gow [29]	1980-2012	GCC	GDP, EC, CO_2	Decomposed Gini	GDP → EC, GDP X CO_2
Sbia et al. [56]	1975-2011	UAE	FDI, clean energy, OP, CO_2, GDP	ARDL, VECM	GDP and clean energy → EC
Shahbaz et al. [57]	1975-2011	Indonesia	GDP, EC, FD, OP, CO_2	ARDL, VECM Granger causality	EC → CO_2, FD ↔ CO_2
Solarin and Lean [58]	1965–2013	India and China	NG, GDP, CO_2	Hatemi-J, TYDL GC	NG ↔ Y
Wasti and Zaidi [59]	1971-2017	Kuwait	CO_2, EC, GDP, trade liberalization	ADF, Phillips-Perron	EC ↔ CO_2

Note. The table defined selected references which presented studies about economic growth, environment, and energy (created by the author). Variable symbols: NG: natural gas consumption; BC: biological capacity; EF: ecological footprint; FDI: foreign direct investment; FD: financial development; EC: energy consumption; GDP: economic growth; HC: human capital; CO_2: carbon dioxide emissions; OP: trade openness; L: labor; K: capital; Electric: electric consumption. Causality symbols: ↔, bidirectional causality; →, causality from to; X, no causality.

at a critical juncture where sustainable practices are paramount for both food security and environmental conservation [12–14, 69]. The effectiveness of institutional arrangements becomes apparent in steering these sectors towards environmentally sustainable pathways. Strong governance, transparent regulations, and collaborative international efforts are crucial in ensuring that economic growth is not achieved at the expense of environmental degradation. Institutions that prioritize sustainability can act as guardians of environmental security, promoting responsible business practices and holding entities accountable for their ecological footprint [70]. As we strive to realize the sustainable development goals, technological innovation emerges as a key player. The delicate balance between economic growth and environmental security hinges on innovative solutions that decouple progress from resource depletion. Financial development, when aligned with sustainable investment practices, can propel the transition to a green economy. Simultaneously, a judicious approach to energy use, leveraging technological advancements, can drive economic growth while mitigating environmental impact [71]. In essence, the pursuit of sustainability and economic growth is not a zero-sum game but a delicate equilibrium that demands thoughtful institutional arrangements, responsible practices, and technological ingenuity. Only through such an integrated approach can we ensure a future where prosperity is harmonized with environmental security, paving the way for a resilient and sustainable global society [12–14].

3. Data and Methodology

3.1. Data. This study used annual data for the period 1980–2019 to assess the causal relationship among the variables of GCC countries, namely, Saudi Arabia, Kuwait, Bahrain, Qatar, United Arab Emirates, and Oman. To achieve the aims of this study, four variables are used which are gross domestic product (GDP) proxies of economic growth, carbon dioxide (CO_2) emission for environment pollution, energy production from natural gas (NG) proxies of clean energy production, and energy production from petroleum and other liquids (OIL) proxies for nonclean energy production. GDP measured in thousands of constant international (2017 US$), NG and OIL have been obtained from Energy Information Administration (EIA), measured in metric million British thermal unit (MMbtu), and CO_2 is obtained EIA and measured in tons of carbon dioxide emissions. We have used population series retrieved from World Development Indicators (WDI), to convert all variables into per capita (see Table 4).

3.2. Descriptive Analysis. As shown in Table 5, the descriptive statistics shows that the distribution and variability of the data for GDP per capita, carbon dioxide emissions, natural gas energy production, and energy from oil and other liquid production all are in natural log forms.

3.3. Panel Unit Root Tests. For testing the stationarity of the data, we used in this study verity panel unit root tests such as the augmented Dickey-Fuller (ADF) [72], Phillips-Perron (PP) [73], Levin and Zhang [74] (LLC), and Mitić et al. [75] (IPS). Thus, if the absolute P values of these tests are less than 5 percent critical value, it means that the tested variable does not have unit root or stationary. On the other hand, if the result is greater than 5 percent critical value, it means that the data is nonstationary. As shown in Table 6, we can conclude that the variables are combination of $I(0)$ and $I(1)$ process.

Table 4: Data.

Code	Definition	Source
CO_2	CO_2 emissions (tone CO_2)	Energy Information Administration (EIA)
GDP	Real GDP per capita (in M 2017US$)	PTW-10
URB	Percentage urbanization (%)	World Development Indicators (WDI)
PNG	Produced energy from natural gas	Energy Information Administration (EIA)
POIL	Produced energy from petroleum and other liquids	Energy Information Administration (EIA)
PE	Total produced energy	Energy Information Administration (EIA)
CNG	Consumed energy from natural gas	Energy Information Administration (EIA)
COIL	Consumed energy from petroleum and other liquids	Energy Information Administration (EIA)
CE	Total consumed energy	Energy Information Administration (EIA)

Note. The table defined selected variables with source (created by the author).

Table 5: The descriptive statistics.

	lnCE	lnPE	lnCOIL	lnPOIL	lnCNG	lnPNG	lnURB	lnGDP	$\ln CO_2$
Mean	-0.96	0.32	-1.99	-0.07	-1.56	-1.40	-0.17	3.71	3.09
Median	-0.80	0.09	-1.95	-0.03	-1.58	-1.41	-0.15	3.76	3.26
Maximum	0.13	1.68	-1.07	1.50	0.00	1.03	0.00	5.50	4.11
Minimum	-2.88	-1.55	-3.55	-4.47	-4.68	-4.68	-0.74	2.27	1.22
Std. dev.	0.65	0.65	0.59	0.89	0.88	1.07	0.14	0.74	0.62
Skewness	-0.76	0.24	-0.60	-1.08	-0.39	0.19	-1.23	0.09	-0.79
Kurtosis	3.29	2.00	2.77	4.75	2.59	2.93	5.34	2.16	3.26
Jarque-Bera	23.73	12.27	15.01	77.07	7.77	1.48	115	7.33	25.41
Probability	0.00	0.00	0.00	0.00	0.02	0.48	0.000	0.03	0.00
Sum	-231.30	76.46	-476.67	-16.87	-373.54	-335.95	-40.11	890.43	742.07
Sum sq. dev.	99.46	102.06	82.88	191.21	186.57	271.51	4.59	129.76	93.23
Observations	240	240	240	240	240	240	240	240	240

Note. The table presents the results given by E-views (created by the author).

3.4. Methodology. Given that the variables are combination of $I(0)$ and $I(1)$ process, then we applied panel autoregressive distributed lag (ARDL) approach suggested by Pesaran et al. [76]. ARDL is used by many scholars as shown in the literature review section. The main advantage lies in its flexibility, compared to other cointegration approaches. Moreover, it can be applied whether the variables involved are purely stationary $I(0)$ or difference stationary $I(1)$, a mixed or mutually cointegrated. For the stability of data, each variable is presented in its natural log and the error term is added to the models. So, there would be two main models which are pollution model and economic growth model. Each of these main model contains six submodels. The twelve models can simply state as

$$\ln CO_{2t} = \beta_1 \ln GDP_t + \beta_3 \ln URB_t + \beta_4 \ln PE_t + \varepsilon_t, \quad (1)$$

$$\ln CO_{2t} = \beta_1 \ln GDP_t + \beta_3 \ln URB_t + \beta_4 \ln PNG_t + \varepsilon_t, \quad (2)$$

$$\ln CO_{2t} = \beta_1 \ln GDP_t + \beta_3 \ln URB_t + \beta_4 \ln POIL_t + \varepsilon_t, \quad (3)$$

$$\ln CO_{2t} = \beta_1 \ln GDP_t + \beta_3 \ln URB_t + \beta_4 \ln CE_t + \varepsilon_t, \quad (4)$$

$$\ln CO_{2t} = \beta_1 \ln GDP_t + \beta_3 \ln URB_t + \beta_4 \ln CNG_t + \varepsilon_t, \quad (5)$$

$$\ln CO_{2t} = \beta_1 \ln GDP_t + \beta_3 \ln URB_t + \beta_4 \ln COIL_t + \varepsilon_t, \quad (6)$$

$$\ln GDP_t = \beta_1 \ln CO_{2t} + \beta_2 \ln K_t + \beta_3 \ln PE_t + \varepsilon_t, \quad (7)$$

$$\ln GDP_t = \beta_1 \ln CO_{2t} + \beta_2 \ln K_t + \beta_3 \ln PNG_t + \varepsilon_t, \quad (8)$$

$$\ln GDP_t = \beta_1 \ln CO_{2t} + \beta_2 \ln K_t + \beta_3 \ln POIL_t + \varepsilon_t, \quad (9)$$

$$nGDP_t = \beta_1 \ln CO_{2t} + \beta_2 \ln K_t + \beta_3 \ln CE_t + \varepsilon_t, \quad (10)$$

$$\ln GDP_t = \beta_1 \ln CO_{2t} + \beta_2 \ln K_t + \beta_3 \ln CNG_t + \varepsilon_t, \quad (11)$$

$$\ln GDP_t = \beta_1 \ln CO_{2t} + \beta_2 \ln K_t + \beta_3 \ln COIL_t + \varepsilon_t. \quad (12)$$

The β_1, β_2, and β_3 represent the slope coefficients, t is the period (1980–2019), and ε is the error term. The ARDL approach can estimate the long-run and short-run parameters of the model simultaneously. For implementing the ARDL approach requires two steps. The first step consists of testing for the existence of a long-run relationship, between the relevant variables in the existence of an error correction, based on the F test. The second step of the ARDL, after making sure the F tests in the first step is within accepted limits, is to estimate the coefficients of the long-run relations. Therefore, the ARDL models of the long-run

Table 6: Panel unit root tests.

	I (0)				I (1)			
	LLC	IPS	ADF	PP	LLC	IPS	ADF	PP
$\ln CO_2$	-1.3*	-0.9	15.1	24	-5.8***	-7.3***	76.1***	168.8***
lnGDP	-0.2	0.7	8.2	9.6	-5.1***	-6.1***	60.6***	95.9***
lnURB	-1.86**	-0.26	12	72***	-3.2***	-2.5***	26**	29***
lnPNG	-1.5*	-0.8	16.5	27.5***	-7.7***	-9.1***	98.7***	159.4***
lnCNG	-2.4***	-2.3***	24.9**	36.9***	-8.3***	-9.8***	106.2***	174.4***
lnPOIL	0.04	-1.5*	29.3***	27.6***	-2.77**	-5.3***	56.1***	105.7***
lnCOIL	0.15	1	5	8.5	-0.5	-7.7***	80.6***	173.3***
lnPE	-0.9	-2.8***	35.7***	34.3***	-4.9***	-6.4***	65.9***	123.7***
lnCE	-1.4*	-0.7	14.3	23.5**	-6.1***	-8.2***	87.2***	181.8***

Note. The table presents the results given by E-views (created by the author); with *($pv > 10\%$); **($pv > 5\%$); ***($pv > 1\%$).

relationship between economic growth and carbon emissions and clean energy production can be written as

$$\begin{aligned}\Delta Y_{it} &= a + \pi_0 Y_{it-1} + \pi_1 X_{1it-1} + \pi_2 X_{2it-1} + \cdots + \pi_j X_{mit-1} \\ &\quad + \sum_{j=1}^{k1} \beta_0 \Delta Y_{it-1} + \sum_{j=1}^{k1} \beta_{1i} \Delta X_{1it-2} \\ &\quad + \sum_{j=1}^{k1} \beta_{2i} \Delta X_{2it-1} + \cdots + \sum_{j=1}^{kj} \beta_{mi} \Delta X_{mit-j} + \varepsilon_{it},\end{aligned} \tag{13}$$

where $\varnothing$ is the drift components, $\varnothing 1$ to $\varnothing 6$ are the error correction dynamics, $Y1$ to $Y6$ are the long-run relationship among variables, Δ is the first difference operator, and ε is the white noise term. The F-statistics tests the null hypotheses of no cointegration: H0, $y1 = y2 = y3 = y4 = y5 = y6 = 0$, against the alternative of H1, $y1 \neq y2 \neq y3 \neq y4 \neq y5 \neq y6 \neq 0$. The critical values of the F-statistics are reported by Pesaran and Pesaran [77].

3.4.1. Panel Cointegration Test. Before the panel error correction model is estimated, it is important to find the presence of cointegration among the variables. We conducted the panel cointegration test proposed by Pedroni [78], which can be expressed as

$$Y_{it} = \alpha_i + \beta_1 X_{1it} + \cdots + \beta_{mi} X_{mit} + \eta_{it}, \tag{14}$$

where a_i is the unobservable individual country specific effect, $t = 1, \ldots T$ and $I = 1, \cdots N$; t is the number of observation over time; I is cross-sectional units; and η_{it} represents error term. By taking the first difference of the equation and performing cointegration on residual, the error term is modeled in a first autoregressive process as

$$\eta_{it} = \Phi_i \eta_{it-1} + \mu_{it}. \tag{15}$$

4. Results

The study was conducted through estimating two main models: the first for explaining environmental pollution and the second for explaining economic growth. Each main model branches into 6 submodels, with the energy factor varying according to the type of energy as follows: energy production from natural gas (PNG), energy consumption from natural gas (CNG), energy production from petroleum liquids (POIL), energy consumption from petroleum liquids (COIL), total energy production (PE), and total energy consumption (CE). The construction of the standard models relied on the autoregressive distributed lag (ARDL) methodology using panel data. In addition, the results of the first main model were divided into two parts: the first part includes three models to estimate the relationship on the energy production side (total energy produced, energy produced from natural gas, and energy produced from petroleum liquids), while the second part contains three models to estimate the relationship on the energy consumption side (total energy consumption, energy consumption from natural gas, and energy consumption from petroleum liquids). The data were used in their natural logarithmic form, and an error term was added to the models. Also, the Pedroni residual cointegration test was conducted for six group of variables, and each group has different energy variables (see Table 7). The results of the unit root tests show that all study data are stable at the first difference, but not all are stable at the level. The results of the integration test, using the Pedroni methodology, indicate the presence of long-run cointegration (panel ARDL) in cross-sectional data. This supports the existence of long-run cointegration in at least one direction.

Based on the models' test, it is noteworthy that the parameter related to per capita GDP is positive and significant in the long term. This means that the economic growth factor has a long-term positive and significant impact in two out of three models, while the relationship varies in the short term, becoming negative and significant in all three models. On the aspect of human development, the results indicate that the literacy rate has a positive and significant impact in the long term on environmental pollution in all three models, with no significant results in the short term. Regarding energy production, the results show a positive and statistically significant long-term and short-term relationship for

Table 7: The Pedroni residual cointegration test.

	PNG	CNG	POIL	COIL	PE	CE
Within group						
Panel v-statistics	-0.21	-0.47	-1.16	-0.09	-0.7	-0.68
Panel rho-statistics	0.56	0.06	0.96	0.42	0.51	0.47
Panel PP-statistics	-0.14	-1.53*	0.2	-0.69	-0.04	-0.73
Panel ADF-statistics	-1.18	-1.81**	0.38	-0.63	0.1	-0.63
Between group						
Panel rho-statistics	0.69	0.21	0.88	-0.01	0.57	0.21
Panel PP-statistics	-0.34	-1.57*	-0.24	-1.61*	-0.42	-1.35*
Panel ADF-statistics	-1.83**	-1.89**	-0.06	-2.97***	-0.18	-1.73**

Note. The table presents the results given by E-views (created by the author); with *($pv > 10\%$); **($pv > 5\%$); ***($pv > 1\%$).

all types of energy production with environmental pollution (see Table 8). This indicates that energy production, not just energy consumption, has a negative impact in both the long and short terms on environmental pollution. Despite natural gas having lower carbon emissions than oil, the results suggest that the Gulf Cooperation Council countries may not have reached a sufficient percentage of natural gas utilization in energy production compared to the overall energy production, thus failing to effectively mitigate environmental pollution.

The results indicate the presence of a positive and statistically significant long-term relationship between all types of energy consumption and environmental pollution, as well as for the short-term relationship (see Table 9).

According to the long-run and short-run results of the panel ARDL, there are no strongly significant findings indicating that environmental pollution is a factor in short-term economic growth. In the long term, there are inconclusive results suggesting a positive relationship, particularly evident in the model of total energy production. As for the urbanization factor, all results are positive and significant only in the long term (see Table 10).

It is noticeable from the results of the models that total energy consumption has a positive and significant impact on economic growth in the long term. However, in the short term, the results were not significant. As for the impact of environmental pollution on economic growth, there were no strong and significant results. In the model of energy consumption from petroleum liquids, a positive relationship with a significance level of 8% was observed. In the model of total energy consumption, a negative relationship with a significance level of 4% was found in the long term, and the results were not significant in the short term. Regarding the urbanization factor, all results are positive and significant only in the long term (see Table 11).

Regarding environmental pollution, the ARDL model shows that both short- and long-run factors impact pollution. The impact of economic growth on environmental pollution is significant and positive in the short run but varies in the long run. The results suggest that total energy consumption has a significant and positive long-run effect on pollution, while short-run relationships are inconclusive. Carbon emissions have a significant and negative long-run effect on pollution, with a strong statistical significance. The Granger causality test indicates the presence of a causal relationship. The results suggest that the production of oil causes environmental pollution from natural gas and total energy consumption. Additionally, economic growth is causally linked to the consumption of oil. The causal relationships primarily involve pollution, except for the consumption aspect, for which the causal relationship with economic growth remains uncertain. The study discusses the relationship between consumption, production of total energy, and environmental pollution in the GCC countries. It highlights the need for strategic measures to protect the environment and develop cleaner energy sources to improve energy efficiency. The results confirm the expected association between consumption, production of total energy, and environmental pollution, consistent with previous studies and economic theory. Therefore, it is necessary to implement strategies that can enhance environmental protection and promote the development of cleaner energy sources to improve energy efficiency. In terms of clean energy production and consumption, the results indicate that other GCC countries might be contributing more to environmental pollution due to their insufficient usage of natural gas as an energy source compared to their overall energy consumption. Therefore, it is crucial for GCC countries to focus on increasing the use of natural gas as an energy source and cooperate in conserving the environment. Furthermore, the results show that economic growth significantly affects environmental pollution, while the relationship between pollution and economic growth differs between the short and long run. This might support the environmental Kuznets curve theory, which suggests that pollution initially increases with economic growth but eventually decreases as countries achieve higher levels of economic development in the long run. Overall, the findings call for stronger efforts in reducing environmental pollution, promoting clean energy consumption, and ensuring sustainable economic growth to protect the environment in the GCC region.

5. Discussion

Energy is one of the most important sources of economic growth due to the effort and time it saves. It serves as the driving force behind productive machinery. However, the

Table 8: Long-run and short-run results of the panel ARDL—pollution models of production energy.

Produced energy from natural gas ARDL (1.1.1.1) Dependent variable—lnCO_2			Produced energy from petroleum ARDL (4.1.1.1) Dependent variable—lnCO_2			Total produced energy ARDL (1.1.1.1) Dependent variable—lnCO_2		
	Coefficient	*t*-statistic		Coefficient	*t*-statistic		Coefficient	*t*-statistic
Long-run results of the panel ARDL—pollution models of production energy								
lnGDP	0	0.06	lnGDP	0.80***	12.53	lnGDP	0.49***	9.13
lnURB	0.02	1.38	lnURB	0.28**	2.08	lnURB	0.47***	8.25
lnPNG	0.69***	26.26	lnPOIL	0.65***	3.36	lnPE	0.98***	8.48
Short-run results of the panel ARDL—pollution models of production energy								
ECM	-0.34***	-2.9	ECM	-0.13*	-1.88	ECM	-0.17*	-1.94
ΔlnGDP	-0.02	-0.4	ΔlnGDP	-0.02	-0.35	ΔlnGDP	-0.09	-1.37
ΔlnURB	0.19	0.39	ΔlnURB	-0.24	-0.61	ΔlnURB	0.12	0.45
ΔlnPNG	0.29***	2.95	ΔlnPOIL	0.23***	2.98	ΔlnPE	0.40***	3.9
C	1.34***	2.8	*C*	-0.53*	-1.94	*C*	-1.02*	-1.96

Note. The table presents the results given by E-views (created by the author); with *(*pv* > 10%); **(*pv* > 5%); ***(*pv* > 1%).

Table 9: Long-run and short-run results of the panel ARDL—pollution models of consumption energy.

Consumed energy from natural gas ARDL (3.4.4.4) Dependent variable—lnCO_2			Consumed energy from petroleum ARDL (4.1.1.1) Dependent variable—lnCO_2			Total consumed energy ARDL (1.1.1.1) Dependent variable—lnCO_2		
	Coefficient	*t*-statistic		Coefficient	*t*-statistic		Coefficient	*t*-statistic
Long-run results of the panel ARDL—pollution models of consumption energy								
lnGDP	0.05***	3.95	lnGDP	0	-0.04	lnGDP	0	-0.41
lnURB	-0.04***	-3.2	lnURB	-0.08***	-2.84	lnURB	0.02***	-4.22
lnCNG	0.82***	74.72	lnCOIL	0.75***	7.74	lnCE	1.01***	80.96
Short-run results of the panel ARDL—pollution models of consumption energy								
ECM	-0.66**	-2.42	ECM	-0.33***	-5.05	ECM	-0.45***	-6.63
ΔlnGDP	-0.04	-1.52	ΔlnGDP	0.09	1.16	ΔlnGDP	0	-0.18
ΔlnURB	0.47	0.53	ΔlnURB	-0.45	-1	ΔlnURB	0.13	0.38
ΔlnCNG	0.09	0.43	ΔlnCOIL	0.07	0.79	ΔlnCE	0.40***	3.54
C	3.10**	2.34	*C*	1.96***	5.65	*C*	1.96***	6.39

Note. The table presents the results given by E-views (created by the author); with *(*pv* > 10%); **(*pv* > 5%); ***(*pv* > 1%).

environmental implications of energy consumption vary based on its sources. Some energy sources contribute to pollution, while others, especially renewable ones, have less impact. Ensuring energy security and independence has become a critical concern for decision-makers worldwide, given the increasing demand for energy and the uncertain supply. This poses challenges for Gulf Cooperation Council (GCC) countries, despite their substantial reserves of oil and gas and strong financial positions. They seek to replace traditional energy sources with renewable ones over the long term. Consequently, GCC countries are urged to balance economic development with environmental preservation. Air pollution, particularly caused by carbon emissions, poses one of the most significant environmental challenges and has far-reaching consequences. Various economic activities are responsible for this type of pollution, leading to the emergence of the concept of sustainable development. Sustainable development seeks to harmonize environmental and economic interests for an economically sustainable future. The growing scope of environmental pollution-related problems has elevated the importance of environmental issues, making GCC countries recognize them as essential components of society's well-being and development. Overall, the study emphasizes the importance of clean and renewable energy sources to promote sustainable economic growth while safeguarding the environment, in line with the principles of social and environment responsibilities, and the global call for sustainable development. The expansion of environmental pollution-related problems has driven society to give greater importance to environmental issues. Gulf Cooperation Council (GCC) countries are considered part of this community that prioritizes environmental matters. The world debate about climate change emphasizes that the widening scope of environmental pollution-related problems has led society to attach more significance to environmental issues. In this context, GCC

Table 10: Long-run and short-run results of the panel ARDL—economic growth models—production energy.

Produced energy from natural gas ARDL (1.1.1.1) Dependent variable—lnGDP	Coefficient	t-statistic	Produced energy from natural gas ARDL (1.1.1.1) Dependent variable—lnGDP	Coefficient	t-statistic	Produced energy from natural gas ARDL (1.2.2.2) Dependent variable—lnGDP	Coefficient	t-statistic
Long-run results of the panel ARDL—economic growth models—production energy								
$lnCO_2$	-0.79**	-2.2	$lnCO_2$	1.67***	9.49	$lnCO_2$	1.71***	7.49
lnURB	-2.94*	-1.76	lnURB	-4.90***	-4.85	lnURB	-4.86***	-4.36
LnPNG	1.46***	6.41	lnPOIL	-0.60***	-2.89	lnPE	-0.27	-0.87
Short-run results of the panel ARDL—economic growth models—production energy								
ECM	-0.10***	-2.68	ECM	-0.09	-1.45	ECM	-0.11*	-1.88
$\Delta lnCO_2$	0.20***	2.81	$\Delta lnCO_2$	-0.01	-0.15	$\Delta lnCO_2$	-0.16	-1.38
ΔlnURB	-7.02	-0.94	ΔlnURB	-7.52	-1.15	ΔlnURB	10.44	1.65
ΔlnPNG	-0.04	-0.36	ΔlnPOIL	0.23	1.33	ΔlnPE	0.35*	1.82
C	0.71***	3.12	C	-0.17	-1.17	C	-0.18	-1.51

Note. The table presents the results given by E-views (created by the author); with *($pv > 10\%$); **($pv > 5\%$); ***($pv > 1\%$).

Table 11: Long-run and short-run results of the panel ARDL—economic growth models—consumption energy.

Consumed energy from natural gas ARDL (1.1.1.1) Dependent variable—lnGDP	Coefficient	t-statistic	Consumed energy from natural gas ARDL (1.1.1.1) Dependent variable—lnGDP	Coefficient	t-statistic	Consumed energy from natural gas ARDL (1.1.1.1) Dependent variable—lnGDP	Coefficient	t-statistic
Long-run results of the panel ARDL—economic growth models—consumption energy								
$lnCO_2$	1.75***	3.23	$lnCO_2$	-0.31	-1	$lnCO_2$	-2.78**	-2.39
lnURB	-2.26	-1.17	lnURB	7.47***	3.25	lnURB	-4.98***	-2.86
lnCNG	-1.24***	-3.92	lnCOIL	1.77***	6.2	lnCE	4.61***	4.26
Short-run results of the panel ARDL—economic growth models—consumption energy								
ECM	-0.09*	-1.96	ECM	-0.11***	-2.77	ECM	-0.11***	-3.23
$\Delta lnCO_2$	0.25**	2.49	$\Delta lnCO_2$	0.18	1.13	$\Delta lnCO_2$	-0.13	-0.3
ΔlnURB	-9.96	-1.32	ΔlnURB	-9.87	-1.6	ΔlnURB	-8.64	-1.36
ΔlnCNG	-0.05	-0.4	ΔlnCOIL	0.1	0.71	ΔlnCE	0.34	0.93
C	-0.33*	-1.82	C	0.99***	2.75	C	1.74	3.22

Note. The table presents the results given by E-views (created by the author); with *($pv > 10\%$); **($pv > 5\%$); ***($pv > 1\%$).

countries are recognized as part of the community that addresses and considers environmental concerns as crucial. The study discusses the results of various tests related to unit root, integration, and Granger causality. It highlights the presence of long-run cointegration among variables and the causal relationship between consumption, production of total energy, and environmental pollution. The results indicate that all study data are stable at the first difference but not all are stable at the level. The Pedroni and Johansen tests support the existence of long-run cointegration. The ARDL-panel estimation shows that energy consumption and production have significant and positive effects on environmental pollution in the short and long run as the same result was concluded by Alam et al. [12–14], Hamid et al. [62], Alam et al. [12–14], Pachiyappan et al. [63], and Guang-Wen et al. [66]. However, the relationship between economic growth and environmental pollution differs in the short and long run as the same result was concluded for the panel estimation through many studies revealed by Sweidan and Elbargathi [9], Mahmood and Furqan [7], Kahouli and Chaaben [8], and AlKhars et al. [10]. In the short run, economic growth has a significant positive effect on pollution, while in the long run, the effect is negative. Regarding the Granger causality tests, there is evidence of a causal relationship between consumption, production of total energy, and pollution. Consumption of oil and natural gas leads to pollution, while the relationship between economic growth and pollution is inconclusive. In summary, the results show the importance of addressing environmental issues and promoting sustainable energy consumption and production practices. These findings have been a consistency with the previous studies of Alam [79], El-Agouz [3], Jaradat [4], Farooq et al. [5], and Gharib et al. [15]. Moreover, the results regarding the relationship between energy consumption, production, and environmental pollution align with many previous studies and general economic theory. Therefore, strategies should be adopted to enhance the efficiency of energy consumption in the region, contributing to environmental protection. Additionally, the development of cleaner energy sources and the implementation of policies to curb environmental pollution resulting from energy consumption are imperative. As for the production and consumption of clean energy, the results affirm its contribution to environmental pollution in Gulf Cooperation Council (GCC) countries. This could be attributed to these countries not yet reaching a sufficient percentage of natural gas utilization compared to the total energy produced, which plays a significant role in reducing environmental pollution. In this context, GCC countries should increase the use of natural gas and other clean sources of energy to preserve the environment. Regarding the results of the environmental pollution factor model, they indicate that economic growth influences environmental pollution, and the nature of the relationship between them (positive or negative) differs in the short and long term. This observation may support the environmental Kuznets curve (EKC) theory due to the variation in the sign of the economic growth parameter as a factor of environmental pollution in the short term compared to the long term. These results presented a strong consistency with the studies of Alam et al. [12–14], Manigandan et al. [71], Shabbir Alam et al. [69], and Hamid et al. [70]. The results of the applied study emphasize the contribution of energy consumption and production to environmental pollution in GCC countries. Therefore, it is essential to develop policies aimed at increasing the efficiency of energy consumption and transitioning towards cleaner energy sources. Although the results also show that consumption and production of clean energy contribute to pollution, this may be attributed to the fact that the use of natural gas is not entirely included in the data. To mitigate environmental pollution, GCC countries should increase the use of clean energy sources to reduce pollution caused by natural gas consumption. Increasing the share of clean energy in the energy mix is crucial for achieving a cleaner environment and sustainable economic growth.

6. Conclusion

The study delves into the multifaceted relationship between energy consumption, economic growth, and environmental pollution in Gulf Cooperation Council (GCC) countries. The investigation, substantiated by rigorous tests on unit root, integration, and Granger causality, reveals significant dynamics. It is evident that while energy is a linchpin for economic progress, the environmental consequences vary based on energy sources, necessitating a strategic shift towards renewable alternatives. The implications of the findings extend to both theoretical and practical realms. The theoretical understanding of long-term cointegration among variables provides a foundation for future research in the realm of energy economics. Practically, the study emphasizes the critical need for policy interventions that prioritize clean energy sources, aligning with global calls for sustainable development. Policymakers in GCC countries are urged to invest in renewable energy, not only to diversify their economies but also to mitigate the negative environmental impacts associated with traditional energy sources. However, this study is not without its limitations. The data may not capture the entire scope of clean energy usage, particularly in the case of natural gas. Additionally, the relationship between economic growth and pollution remains inconclusive in the short run, pointing towards the need for nuanced policy considerations. Furthermore, the study acknowledges the limitations inherent in the complexity of the relationship between economic growth, clean energy, and environmental pollution. In light of these considerations, future research endeavors should focus on refining data collection methodologies to offer a more comprehensive understanding of energy usage patterns. Additionally, a more in-depth exploration of the nuanced relationship between economic growth and environmental impact is warranted. Policymakers are encouraged to foster international collaborations and knowledge exchange to implement effective, context-specific policies that promote sustainable energy practices. As the world grapples with environmental challenges, the findings of this study contribute to the ongoing dialogue, advocating for a cleaner, more sustainable future for GCC countries and beyond. The findings can help inform policies and strategies to mitigate environmental pollution and achieve sustainable economic growth in the region. Despite the importance of gross domestic product (GDP) as a measure of economic growth, it is necessary to reconsider its use in a way that reflects our identity and culture while considering other economic aspects such as income and wealth distribution. Gulf Cooperation Council (GCC) countries face significant challenges in their economic diversification efforts, as their heavy reliance on oil and its derivatives poses risks due to fluctuating oil prices and negative environmental impacts. To achieve economic diversification, GCC countries can invest in sectors like manufacturing and services, attract foreign investments, optimize government spending, and support private sector growth to enhance income distribution. Investment in renewable energy is a crucial area for sustainable economic growth. Investing in renewable energy will increase the availability of oil and gas for export, reduce local energy prices, and lower the cost of energy subsidies. It will also help in mitigating the negative environmental impacts of energy production and consumption.

6.1. Recommendations for Policymakers

(i) Investment in renewable energy: policymakers are urged to prioritize substantial investments in renewable energy infrastructure. This not only aligns with global sustainability goals but also mitigates the environmental impact associated with traditional energy sources

(ii) Diversification efforts: to reduce the heavy reliance on oil and its derivatives, GCC countries should intensify efforts to diversify their economies. Policymakers should focus on sectors like manufacturing and services, attracting foreign investments and optimizing government spending to enhance income distribution

(iii) Optimizing energy subsidies: policymakers should consider optimizing energy subsidies to encourage responsible energy consumption. Aligning subsidies with clean energy practices can incentivize individuals and industries to adopt environmentally friendly alternatives

(iv) International collaboration: foster international collaborations and knowledge exchange to implement effective, context-specific policies. Learning from global best practices and sharing experiences can accelerate the transition towards sustainable energy practices

(v) Data refinement: recognizing the limitations in data collection, policymakers should invest in refining methodologies to capture the entire scope of clean energy usage. A more comprehensive understanding of energy patterns is essential for informed decision-making

To enhance the understanding of the nexus between economic growth, clean energy, and environmental pollution, it is imperative to delve into specific aspects through targeted studies. Investigating the impact of clean energy investments on economic growth within the context of the Gulf Cooperation Council (GCC) countries and comparable regions (Southeast Asian region: Singapore, Malaysia, Thailand, and Indonesia) would provide valuable insights. These countries share similarities with the Gulf Cooperation Council (GCC) nations, such as rapid economic development, increasing energy demands, and environmental challenges. Exploring how these Southeast Asian nations navigate the balance between economic growth and environmental sustainability through clean energy initiatives would provide valuable insights for global discussions on sustainable development. Additionally, examining the effectiveness of existing policies and initiatives aimed at promoting clean energy and mitigating environmental pollution could offer practical recommendations for sustainable development. Collaborative research endeavors focusing on the unique characteristics of the GCC countries and similar regions would contribute to a more nuanced comprehension of this complex relationship.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors confirm that, upon careful examination, there are no conflicts of interest to disclose in connection with this manuscript.

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