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The nexus between economic growth, urbanization, technological advancement, and CO2 emissions: Where does the GCC stand?

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ABSTRACT

Most countries, particularly developing and growing economies, have the primary goal of achieving greater economic growth in order to improve living standards. However, a boost in economic activity raises energy demand, which in turn raises carbon dioxide emissions and deteriorates the environment. This paper investigates the effect of economic growth, energy consumption, and research and development on CO2 emissions in Gulf Council Cooperation (GCC) countries. The study uses the Vector Error Correction Model to investigate the short- and long-run synergy between variables over the period 2000–2022. The results indicate that boosting economic activity requires more energy consumption and will increase CO2 emissions in the long run. Investing in research and development can enhance the quality of the environment, yet the effect of urbanization on CO2 emissions in GCC countries remains unclear. To reduce energy consumption, it is first necessary to expand renewable energy sources and encourage energy-saving techniques. Then, to lower CO2 emissions, the government must promote investments in green technologies, particularly in manufacturing. Third, the government should encourage sustainable urbanization by putting laws in place that encourage the growth of green cities and transportation networks.

Contribution/ Originality: The paper's contribution is to construct a framework that connects CO2 emissions to urbanization, economic expansion, and technical advancement for Gulf Cooperation Council countries, as previous GCC research studies have not thoroughly studied the relationship between these variables in the short and long run.

1. INTRODUCTION

The world's carbon dioxide emissions are rising in line with world population growth and economic expansion, resulting in a growing number of severe issues such as sea level rise and climate change, Ozili (2020) and Liu, Deng, Davis, Giron, and Ciais (2022). Several nations have launched a range of emission reduction programs in response to the climate change challenge, such as developing new energy sources, boosting energy efficiency, and encouraging low-carbon living (Borgi, Mabrouk, Bousrih, & Mekni, 2023; Mori Junior, Fien, & Horne, 2019). According to Rehman, Ma, Ozturk, Murshed, and Dagar (2021) greenhouse gas emissions, particularly carbon dioxide (CO2) emissions, are the primary cause of climate change, one of the world's most significant environmental problems today. The regulations have slowed the increase in CO2 emissions, but the trend of rising emissions remains unfavorable for sustainable development. The Sustainable Development Goals (SDGs) of the United Nations have gained significant international attention to face serious worldwide problems like poverty, inequality, climate change, environmental degradation, and diminishing wealth. To achieve sustainable development for humanity and the planet, the SDGs—

a long-term, global framework for development—are crucial. So, reducing carbon emissions by accelerating the shift to clean energy (Olabi et al., 2022) is crucial to reach the SDGs (Yang, Li, & Guo, 2022).

An important agreement was signed by 198 Parties at the 28th Conference of the Parties, or COP28, in Dubai in December 2023, signaling the beginning of a new era in climate action for the GCC countries. The UAE Agreement included several significant commitments, with an unprecedented mention of moving away from fossil fuels in energy systems and tripling the amount of renewable energy produced.

Additionally, several of the largest oil-producing nations in the world made significant declarations about their commitment to renewable energy. The Gulf Cooperation Council (GCC) countries saw this as a rare chance to emphasize their support for the climate resilience agenda and green energy growth. The Arab Coordination Group (ACG), a strategic partnership comprising international and regional development organizations, announced its commitment to provide US$10 billion until 2030, upholding its previous $24 billion pledge to finance the transition to a green economy. In recent years, the GCC countries have committed to addressing climate change at both the national and regional levels. For example, Oman and the United Arab Emirates (UAE) signed on to NetZero by 2050. Furthermore, the Kingdom of Saudi Arabia (KSA) and the Middle East Green Initiative (MEGI) have pledged to achieve Net Zero status by 2060. In addition to funding initiatives that could support low-carbon technologies such as green hydrogen, the circular carbon economy, increased involvement in carbon markets, and domestic energy efficiency projects, several countries have also committed to reducing methane emissions by at least 30 percent by 2030 by participating in the global methane pledge. Despite all these efforts, the GCC countries are considered to date the most pollutant in the region as they are the main energy suppliers: Akasha, Ghaffarpasand, and Pope (2023). This paper is an attempt to determine which factors can affect CO_2 emissions in the Gulf region to help policymakers formulate strategies to reduce environmental degradation to achieve the targets set for the coming years. Research on the factors influencing CO_2 emissions has increased dramatically over the last 20 years (Andreoni & Galmarini, 2016; Dong, Hochman, & Timilsina, 2020; Henriques & Borowiecki, 2017). According to Liu (2020) many factors, including globalization, renewable energies, research and development, economic expansion, and urbanization, can have an important impact on CO_2 emissions.

According to Grossman and Krueger (1995) the three main elements influencing the environment are economic scale, urbanization, and technological level. Economic scale is the economy's output; higher economic output leads to higher levels of pollution. This is because increased resource investment and energy use are essential for economic growth. Urbanization has an impact on energy use. As cities grow and more people move into them, the need for energy rises. Technology advancements will realize resource efficiency and reduce energy consumption. As a result, the technical level is a major factor influencing pollution and energy intensity. We conduct and expand upon several research investigations based on these three environmental elements.

This paper adds to the body of literature in two ways. First, we attempt to construct a framework using three levels of three key factors that influence CO_2 emissions. The most crucial elements are the following: economic growth, urbanization (through energy consumption), and technological advancement (through R&D). Second, most of the research that has been done so far to examine the link between key factors and carbon emissions in Gulf Cooperation Council countries uses the Ordinary Least Squares (OLS) framework.

The study focuses on climate actions in GCC countries for the period 2000–2022, as these economies have accelerated economic development over the past few decades by implementing several economic reforms. Though there's a chance these policies had negative environmental effects, they may have produced positive economic results. The issue of environmental degradation has been getting worse recently in the GCC countries, most likely due to the economy becoming more industrialized, using fossil fuels more frequently, and the growing number of large cities. In fact, according to IQAir AirVisual (2023)—three of the six GCC nations—Bahrain, Kuwait, and the United Arab Emirates—were among the top 10 most polluted countries in 2023; some cities, including Manama, Kuwait City, and

Dubai, have air pollution levels higher than 52.0(μg/m3), which is more than 500% higher than the World Health Organization (WHO) standard.

The main findings of this paper show a strong long-term impact of the three factors—Gross Domestic Product (GDP) growth, urbanization, and technological development—on CO_2 emissions in GCC countries, but in the short run, the relationship is ambiguous.

Section 2 presents the literature review and the development of the hypothesis. While Section 4 presents the main conclusions, the remainder of 3 exposes the data and methods. Section 5 concludes the paper.

2. LITERATURE REVIEW

Lowering carbon emissions is crucial to reaching the Sustainable Development Goals (SDGs), Yang et al. (2022) and Wills et al. (2022). The United Nations created the Sustainable Development Goals (SDGs), a worldwide framework with four main objectives: eradicating poverty, advancing social justice, safeguarding the environment, and accelerating economic growth, Opoku, Dogah, and Aluko (2022). It has 169 distinct indicators spanning multiple areas and 17 objectives. SDG 13, "Take urgent action to combat climate change and its impacts," is one of them. Its objectives include strengthening coordination and collaboration on climate-related issues, enhancing climate resilience and adaptive ability, and reducing global greenhouse gas emissions, Nathaniel and Adeleye (2021).

2.1. Relationship between CO2 Emissions and Economic Growth

According to Liu (2020) there are significant obstacles to sustainable economic growth worldwide due to carbon emissions caused by climate change. Carbon emissions and economic development have a complex and interdependent relationship. Notably, economic expansion raises carbon emissions, particularly in economies that rely heavily on petroleum, since it causes CO_2 emissions to rise, according to studies by Sharif and Tauqir (2021) and Agbanike et al. (2019). According to Grossman and Krueger (1995) economic growth typically necessitates the utilization of additional resources and technology, leading to a rise in greenhouse gas emissions. As a result, economic expansion impacts the environment

The EKC hypothesis has extensively studied the relationship between environmental deterioration, or CO_2 emissions, and economic growth in the literature. This theory posits an inverse U-shaped relationship between per capita GDP and environmental deterioration. In other words, an inverted U-shaped curve arises when the early stages of economic expansion link environmental degradation to GDP per capita, which then begins to decline at a certain income threshold. As economies expand, there is a chance that environmental quality will increase and environmental deterioration will decrease, according to the EKC hypothesis.

Although much research has explored the state of global warming and climate change, very few have investigated the connection between CO_2 emissions and economic growth, particularly when looking at the profiles of GCC countries. The analysis of the energy growth paradox typically begins with a consideration of the damage that energy causes to the biosphere. While some research Shahbaz, Hye, Tiwari, and Leitão (2013), Azam, Rafiq, Shafique, Zhang, and Yuan (2021), Baz et al. (2021) and Zhang, Chen, and Wang (2021) suggests that energy boosts economic growth, other research shows the opposite (Mendoza-Rivera, Ricardo, García-Pérez, & Luis, 2023).

According to research by Azam, Khan, Abdullah, and Qureshi (2015) CO_2 emissions and economic growth in China, Japan, and the US are positively correlated. They examine the environmental deterioration, as measured by CO_2 emissions, using the profiles of a few economies with higher CO_2 emissions. Li, Chang, Wang, and Zhou (2022) and Pao and Tsai (2010) claim that in the long-run equilibrium for the BRICS countries[1], energy consumption brought on by a major economic expansion has a positive and statistically significant impact on CO_2 emissions. The connection between CO_2 emissions and national economic growth has been examined in other research. For instance,

[1] BRICS organization includes Brazil, Russia, India, China, South Africa, Iran, Egypt, Ethiopia, and the United Arab Emirates.

Yousefi-Sahzabi, Sasaki, Yousefi, and Sugai (2011) investigated this connection and identified a significant positive link between CO_2 emissions and Iran's economic growth. Bouznit and Pablo-Romero (2016) confirmed similar findings on the Algeria profile. Based on the results above, we can develop the following hypothesis:

H_1: There is a positive relationship between economic growth and CO_2 emissions.

2.2. Relationship between CO2 Emissions and Urbanization

The literature has conducted numerous studies on the impact of urbanization on carbon dioxide (CO_2) emissions. Many studies have examined the benefits of urbanization on carbon dioxide emissions (Behera & Dash, 2017; York, Rosa, & Dietz, 2003; Zhang & Lin, 2012). The main cause of the decline in environmental quality is urbanization, which is brought on by city growth and rising energy usage. Evidence presented by Shahbaz, Chaudhary, and Ozturk (2017) demonstrated how urbanization increases demand for housing, food, energy, and transportation while also causing major issues with environmental degradation. In most urban locations, for example, poor sanitation, waste management, and traffic congestion can lead to pollution and health issues.

The literature has used numerous cointegration strategies to examine the relationship between urbanization and CO_2 emissions in both industrialized and developing nations. For example, Liu et al. (2021) used the autoregressive distributed lag cointegration system to examine the link between energy use and demography in a sample from rapidly urbanizing China between 1978 and 2008. The empirical findings show strong, long-term relationships between GDP, energy consumption, and urbanization. Hashmi, Fan, Habib, and Riaz (2021) did a study on the non-linear relationship between urbanization pathways and CO_2 emissions in a group of Asian countries from 1971 to 2014. They used the STIRPAT paradigm to look at the data. Robust dynamic panel data techniques have assessed the long-term impact. The empirical findings indicate that in the largest cities, the link between CO_2 emissions and urbanization is not monotonic. We observe a decrease in long-term CO_2 emissions with the demographic shift from rural to urban economies. However, the growing population in the largest cities has a detrimental effect on the quality of the environment. We can formulate a second hypothesis in this context:

H_2: There is a positive relationship between Urbanization and CO_2 emissions.

2.3. Relationship between CO2 Emissions and Technological Advancement

In academic and research environments, the impact of technological advancement through research and development (R&D) spending across many economic sectors has garnered attention. R&D spending has been crucial in creating new instruments, designs, and strategies that lower CO_2 emissions (Lin & Chen, 2020).

Technological advancement primarily drives long-term economic growth with limited resources. Technological advancement positively impacts energy efficiency, but negatively impacts energy intensity (Yu, Shi, Guo, & Yang, 2021). Ang (2009) used current growth theory as a framework to examine how R&D and technological advancements contribute to reducing of CO_2 emissions. Investment in R&D leads to technological advancement, which reduces energy intensity. Antweiler, Copeland, and Taylor (2001) model was expanded upon by Wei and Yang (2010) to examine the variables influencing CO_2 emissions. According to the study, GDP, industrialization, and free trade all positively impact CO_2 emissions; however, independent research and development, as well as technology imports, help to lower CO_2 emissions. Trade in the Information Communication and Technologies (ICT) sector and foreign direct investment (FDI) are two more sources of technological growth. Elliott, Sun, and Chen (2013) discovered a negative correlation between FDI and energy intensity. The most current study by Khan, Murshed, Dong, and Yang (2021) investigates the roles that export diversification and composite country risks have in lowering carbon emissions. The researchers found that reducing national risks, moving to renewable energy, and fostering technological advancements all contribute to a final decrease in CO_2 emissions. Considering the discussion above, the following third Hypothesis can be established:

H_3: There is a negative relationship between Technological Advancement and CO_2 emissions.

3. METHODOLOGY

This section aims to evaluate the empirical findings for the short- and long-run relationship between CO2 emissions, urbanization, economic growth, and technological advancement in GCC countries. As the world's leading energy suppliers and distributors, the Gulf region must tackle CO2 emissions to fulfill the United Nations' climate action program for the upcoming period. Below, we present the details of the data and the empirical model.

3.1. Data and Descriptive Statistics

We selected a range of economic variables based on their expected relative significance for the CO2 emissions levels of the GCC countries. Different databases were used. The "Statistical Review of World Energy" provided data on energy consumption (EnergyC), clean energy (Clean E), and CO2 emissions (CO2), while the World Bank Tables provided data on GDP growth (GDP) and research and development expenditure (R&D) (see Table 1). We utilized every data set covering the period from 2000 to 2022, conducting an annual estimation analysis using EViews 12. The period from 2000 to 2022 is chosen because the data selected are available only from the year 2000 for all six GCC countries.

To minimize any potential heteroskedasticity effect and stabilize the series variance, an analysis of the logs for the indicators was conducted (using the natural logarithmic approach).

Table 1. Definition of the variables used in the model.

Factor	Variable used	Description	Source
Dependent variable			
Environmental degradation	CO2 emissions (CO2)	Emissions of carbon dioxide resulting from energy use are expressed by kt (Kiloton).	Statistical review of world energy
Independent variables			
Economic growth	GDP growth (GDP)	GDP growth rate as a percentage each year, expressed in US dollars.	World bank (WB)
Technological development	Research and development (R&D)	The overall number of researchers involved in research and development, or R&D, is stated in terms of million.	World bank (WB)
Urbanization	Energy consumption (EnergC)	Energy consumption in thousands of barrels per day	Statistical review of world energy
Control	Clean energy use (Clean)	Waste and renewable energy sources include solid and liquid biofuels, biogas, hydro, geothermal, solar, wind, and tide/Wave/Ocean energy, as well as the use of these energy sources to generate power and heat.	Statistical review of world energy

3.2. Model

The study examines the long- and short-term relationships between urbanization as measured by energy consumption, technical advancement as assessed by research and development spending, environmental degradation as measured by CO2 emissions, and economic growth as measured by GDP growth. Theoretically, the CO2 emissions function relates to energy consumption, research and development expenditure, and GDP growth. Therefore, we could model the CO2 emissions equation as shown in Equation 1:

$$CO2_t = F\left(EnergC_t, GDP_{t,}, R\&D_t\right) \quad (1)$$

Where EnergC, R&D, CO2, and GDP are explained in Table 1. Additional variables, such as clean energy use (Clean), were introduced per the goal of the current analysis. Using the study methodology of Shahbaz and Rahman (2010) and Tang and Tan (2013) the proposed research model can now be expressed as follows:

$$CO2_t = \theta_0 + \theta_1 EnergC_t + \theta_2 GDP_t + \theta_3 R\&D_t + \theta_4 Clean_t + \varepsilon_t \quad (2)$$

Where θ_i is the coefficient to be estimated; $i = 0, \ldots, 4$. And subscripts t denote year; $t = 1, 2, \ldots., 22$.

Vector autoregression analysis (VAR) is the first recommended and practical methodology to predict the joint dynamic behavior of a system of time series equations. However, for the results to be valid, this model requires all the series to satisfy the stationarity criterion at a specific level, in addition to the initial difference. Even so, differencing the data may lead to the loss of crucial information about the relationships between these series, especially the long-run stochastic trend known as the cointegration between the levels. The Vector Error Correction Model (VECM), a different approach first introduced by Johansen (1995) is frequently used to evaluate the validity of level regressions and determine whether a long-run relationship (cointegration) exists between these indicators, according to Indrajaya (2021). Before proceeding, we need to perform a few diagnostic tests to verify the validity of the variables used and the proposed model. The subsequence tables in the upcoming subsections list several of these tests and their results.

4. EMPIRICAL RESULTS

4.1. Descriptives Statistics and Correlation Matrix

Table 2 presents the details of the descriptive statistics analysis regarding the variables used in our investigation. It provides insight into how far each data observation deviates from the mean and enumerates the properties of the time series employed in this investigation. Table 2 divides the output of the descriptive statistics into three primary categories: the sample mean, the median, and the standard deviation from the mean. The Jarque-Bera test determines the regularity of the data distribution.

Table 2. Descriptives statistics.

Statistics	CO2	GDP	Enercons	R&D	Clean
Mean	214.161	239245909	3.755	747.898	98.274
Median	116.768	166227185	1.928	563.890	100
Maximum	667.391	769633172	12.163	2666.015	100
Minimum	21.615	336906291	0.399	61.985	70.5
Std. dev.	191.357	183798311	3.539	722.989	4.395
Skewness	1.010	0.955	1.089	1.496	-4.009
Kurtosis	2.613	3.013	2.753	3.938	21.0777
Jarque-Bera	28.414	24.496	32.242	66.033	2623.650
Prob.	0.675	0.47941	0.996	0.458	0.262
Sum	34480.062	385185914	604.660	120411.656	15822.2
Observations	161	161	161	161	161

The standard deviation for all variables varies from 0.2623 to 0.9969. The hypothesis that the variables are normally distributed was not rejected by the Jarque-Bera diagnostic test results (probability is greater than 0.05). Another crucial test to determine a pairwise correlation between the variables is the correlation test. The results show that the relationships between GDP and CO2 emissions, as well as between energy consumption and CO2 emissions, have the highest correlation coefficients.

4.2. Unit Root Tests

It is essential to perform the unit root test; otherwise, the investigation will not be able to proceed. The goal of the test is to ascertain whether the model's series are stationary in the first difference (I(1)) or in level (integrated of order 0; I(0)); in the second difference (I(2)), however, the series cannot be stationary.

The Augmented Dickey-Fuller (ADF) and Levin, Lin, and Chu (LLC) tests, as shown in Table 3, show that the variables CO2 emissions and energy consumption are stationary in level, whereas the variables Clean, GDP, and R&D are stationary in first difference.

Table 3. Stationarity tests.

Variables	ADF- fisher chi-square		Levin, Lin & Chu t*	
	Level	1st difference	Level	1st difference
CO2	19.8109	-	-4.564***	-
Clean	23.178***	18.425***	3.050	-5.351***
Energy cons	21.731*	-	-5.085***	-
R&D	5.199	203.824***	3.575	-7.329***
GDP	17.179	59.371***	-2.183**	-5.717***

Note: ***,** and * denote a significance level of 1%, 5% and 10% respectively.

4.3. Cointegration Test

Table 3 presents the results, which indicate that there are three cointegration equations among the variables at the 5% level of significance. This shows a long-term correlation between oil consumption, economic growth, research and development, and renewable energy with CO_2 emissions.

Because the data are cointegrated in order one, or I(1), and there is a long-term association between the selected variables, the VECM is an appropriate model to use when examining the short- and long-term effects of CO_2 emissions on GDP, R&D, energy consumption, and renewable energy. These are the empirical outputs from Tables 2 to 4.

Table 4. Johanson Fisher cointegration test.

Hypothesized no. of cointegration equation CE (s)	Trace test Fisher stat		Max-eigen test Fisher stat	
	Statistic	Prob.	Statistic	Prob.
None	61.47	0.000	117.2	0.000
At most 1	94.92	0.000	52.33	0.000
At most 2	62.36	0.000	50.02	0.000
At most 3	21.04	0.000	12.81	0.012
At most 4	11.07	0.025	8.788	0.066
At most 5	5.515	0.238	3.999	0.406
At most 6	8.081	0.088	8.081	0.088

4.4. VECM Results

Table 5 displays the VECM results. For the long-term association, the majority of the coefficients are significant at 10%. According to the findings, a 1% increase in production necessitates a corresponding 1% increase in energy consumption, resulting in a 0.78% increase in CO_2 emissions. This is consistent with the findings of Zhang et al. (2021) and Sharif and Tauqir (2021) who support the idea that increased energy consumption promotes economic growth at the expense of environmental degradation, particularly in countries with abundant petroleum resources. According to Li et al. (2022) substantial economic expansion benefits the BRIC countries over the long term and has a statistically significant impact on CO_2 emissions. Our data supports the first hypothesis (H1), which posits a positive correlation between economic growth and CO_2. Our results confirm hypothesis H1, which states that there is a positive relationship between economic growth and CO_2 emissions.

Long-term environmental degradation and technological advancement have a negative and significant relationship. CO_2 emissions will drop by 0.41% for every 1% increase in research and development spending. Studies by Lin and Chen (2020) and Yu et al. (2021) found that funding research and development promotes technological improvement and lowers energy intensity, thus supporting this relationship. These results confirm Hypothesis H_3: There is a negative relationship between technological advancement and CO_2 emissions.

According to our estimation, the GCC countries' CO_2 emissions are not directly impacted by urbanization. CO_2 emissions will drop by 0.67%. The 1%, 5%, and 10% significance levels do not support the statistical significance of these coefficients. However, other research by Hashmi et al. (2021), Liu et al. (2021) and Liu et al. (2022) affirms that urbanization would result in increased energy consumption, which would worsen environmental degradation. At this stage, we can't confirm Hypothesis H_2: There is a positive relationship between urbanization and CO_2 emissions.

The use of renewable energies, the last indicator we used in our estimation, significantly affects CO_2 emissions. In fact, the results show that increasing the use of clean energies by 1% will reduce CO_2 emissions by 36%. With clean energy technologies growing at a faster rate than fossil fuels since 2019, the GCC countries have a viable approach to cut carbon emissions and fight climate change. Zambrano-Monserrate (2024) confirms that increasing implementation of solar and wind PV has already reduced the demand for fossil fuel consumption, indicating a noticeable transition to cleaner energy sources. Lowering the environmental deterioration in the GCC countries, currently deemed critical, and increasing the deployment of clean energy over fossil fuels, along with raising environmental awareness, will have substantial impacts in the upcoming years.

The error correction mechanism ECM, which examines the rate of convergence to equilibrium from the short run to the long run per year, is shown by the coefficient ECT_{t-1} when looking at the short-run equation. This coefficient has a negative sign and is significant at the 1% significance level. The speed of adjustment towards equilibrium, or the coefficient of equilibrium correction estimate, is -0.0377. This means that there is a significant yearly adjustment of 0.038% for the variables' divergence from the long-term equilibrium to the short-term equilibrium.

Table 5. VECM results.

Long term coefficients	
Lnco2(-1)	1.000
LnGDP(-1)	0.785*
LnEnercons(-1)	-0.673
LnR&D	-0.411*
LnClean(-1)	-36.456*
C	157.803
Short term coefficients	
ECTt-1	-0.037**
Diagnostic test statistics	
R squared	0.152
F-statistic	2.101
Akaike information criterion (AIC)	-2.622
Schwarz criterion (SC)	-2.370
Durbin Watson	2.011
Residual covariance	3.95E-17
Observations	140

Note: ** and * denote a significance level of 1%, and 10% respectively.

4.5. Wald Test

Table 6 presents the Wald test results. Wald/VEC Granger causality has the advantage of combining many lag factors to summarize data on the presence of a short-term causal relationship. One of the beneficial things about Wald/VEC Granger causality is that it brings together a lot of lag factors to show if there is a short-term causal relationship. The VEC Granger causality test, also known as the Wald test, estimates a test statistic based on unrestricted regression. The results of the dynamic short-run relationship can take several forms, including one-way (uni-directional) causality, two-way (two-directional) causality, neutral linkage, or no causal relationship at all. The conventional VEC Granger/Causality Test/Wald test's statistical basis is an asymptotic Chi-square ($\chi 2$) distribution.

The results in Table 6 make it clear that none of the variables (Enercons, GDP, R&D) have chi-square statistics that fail to reject the null hypothesis or are not statistically significant at significance levels of 5%, 1%, and 10%. Therefore, this study cannot establish a short-term relationship between economic growth, urbanization, technological development, and CO_2.

Table 6. Wald test.

Coefficients	Chi-square	Df	Probability	Coefficient	Std. error
Joint	3.211	2	0.200	-	-
C(2)	-	-	-	0.464	0.340
C(3)	-	-	-	0.386	0.336
Joint	7.581	2	0.022	-	-
C(4)	-	-	-	22.427	9.294
C(5)	-	-	-	-16.146	7.710
Joint	1.274	2	0.528	-	-
C(6)	-	-	-	-0.286	0.358
C(7)	-	-	-	-0.293	0.354
Joint	2.331	2	0.311	-	-
C(8)	-	-	-	-0.106	0.079
C(9)	-	-	-	0.069	0.082
Joint	2.331	2	0.311	-	-
C(10)	-	-	-	-0.106	0.079
C(11)	-	-	-	0.069	0.082

5. CONCLUSION POLICY IMPLICATION AND LIMITATIONS

Everyone is concerned about global warming, and governments are searching for practical solutions that will reduce the harmful effects of climate change. Several factors contribute to global warming, with carbon dioxide (CO_2) emissions playing a major role. The goal of this paper—which is especially important for academics, businesses, and policymakers—is to identify potential connections between environmental sustainability, economic growth, renewable energy, and research and development. The primary objective of this study was to ascertain the long- and short-term relationships between economic developments, technical advancement, urbanization, and carbon emissions in GCC countries between 2000 and 2022, given that pollutant emissions are the primary cause of climate change and global warming. According to the VECM model's findings, a 1% increase in output necessitates a corresponding 1% increase in energy consumption, resulting in a 0.78% increase in CO_2 emissions. This positive and substantial coefficient has been verified by studies conducted by Zhang et al. (2021), Li et al. (2022) and Sharif and Tauqir (2021). In the long run, there is a negative and significant relationship between technological advancement and environmental degradation. CO_2 emissions will drop by 0.41% for every 1% increase in research and development spending. Studies by Lin and Chen (2020) and Yu et al. (2021) found that funding research and development promotes technological improvement and lowers energy intensity, supporting this relationship. We estimate that urbanization does not significantly affect the CO_2 emissions of the GCC countries. When looking at the short-run equation, the coefficient ECT_{t-1} shows the error correction mechanism ECM, which examines the rate of convergence to equilibrium from the short run to the long run per year. This coefficient has a negative sign and is significant at the 1% significance level. The speed of adjustment towards equilibrium, or the coefficient of equilibrium correction estimate, is -0.0377. This means that there is a significant yearly adjustment of 0.038% for the variables' divergence from the long-term equilibrium to the short-term equilibrium.

Despite significant technical advances, the GCC countries are at odds about how to combat climate change by reducing CO_2 emissions and adapting to its repercussions. These are pressing concerns for maintaining the environment, protecting lives, and achieving sustainable development objectives. This article suggests that governments should prioritize advancing sustainable development policies that enhance economic growth, reduce carbon emissions, and enhance the quality of life for all residents. To prevent climate change, GCC nations must reduce their greenhouse gas output.

5.1. Policy Implications

The paper's results suggest a few policy recommendations for reducing CO_2 emissions in GCC countries. To reduce energy consumption, first expand the use of renewable energy sources and encourage energy-saving techniques. Subsequently, to lower CO_2 emissions, the government must promote investments in green technologies, particularly in manufacturing, Singh, Adhana, and Garg (2022). Third, the government should encourage sustainable urbanization by putting laws in place that encourage the growth of green cities and transportation networks. Furthermore, it is essential to improve commerce regulations to ensure that businesses operate in an environmentally friendly way.

Fourthly, it recommends that the government take action to promote the use of public transportation to lower the number of private automobiles on the road, which would ultimately result in a decrease in CO_2 emissions. Finally, the recommendation is to implement laws that encourage the adoption of sustainable production and consumption methods. Businesses that adopt sustainable practices, such as using environmentally friendly materials, adopting renewable energy sources, and reducing their waste output, might receive financial support and fiscal incentives from public authorities in GCC countries. It is feasible to encourage consumers to adopt sustainable activities, such as recycling, reducing energy use, and taking public transit, by using educational and awareness-raising campaigns in addition to financial incentives.

To decrease rural-urban mobility, policymakers should direct investments toward rural areas. Moving investments to local areas could discourage foreign investors, nevertheless, in certain high-income nations like the Emirates, Qatar, and Saudi Arabia, where a significant amount of their assets and income generation is concentrated in business centers. However, to maintain the energy efficiency programs for lower carbon emissions while preventing additional urbanization, we must promote rural tourism destination programs.

5.2. Limitations and Future Research Suggestions

The study's focus on GCC nations may limit the findings' generalizability to other regions and countries. Future studies should think about using a mixed-method approach to more thoroughly identify the phenomenon or broadening the scope to include other nations with larger datasets. To tackle environmental degradation and foster sustainable development, decision-makers can make well-informed decisions and devise efficacious solutions by further exploring and comprehending the factors that contribute to CO_2 emissions.

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