

Neetu Kwatra

Fatema Almaqbali

Sarah Al Hashemi

University of Technology and

Applied Sciences

Sultanate of Oman

Carbon Dioxide Emissions and Economic Growth in the Oil, Gas, and Cement Industries of Gulf Countries: A Panel Autoregressive Distributed Lag Analysis for Sustainable Development

Abstract

Purpose: The purpose of this study was twofold: to examine the correlation between CO₂ emissions and economic development in the Gulf Cooperation Council (GCC) countries and to compare the contributions of the oil, gas, and cement sectors to the CO₂ emission in each GCC country.

Study design/methodology/approach: The research design used was descriptive, and cross-sectional independence, panel autoregressive distributed lag, pooled ordinary least squares, and ordinary least squares methods were used to analyze data.

Sample and data: The study used secondary data on CO₂ emissions and gross domestic product (GDP) growth rates from 1981 to 2021 and on the specific contributions of the oil, gas, and cement sectors from 1985 to 2022.

Results: The study found a long-term cointegration between CO₂ emissions and the GDP growth rate in the GCC countries. However, in short term, economic growth did not have a significant impact on CO₂ emissions. The major contributor to the CO₂ emissions in Oman, Kuwait, Saudi Arabia, and Qatar was the oil sector, whereas that in the United Arab Emirates was the cement sector. CO₂ emissions in Bahrain were significantly affected by the gas sector.

Originality/value: The work is original and innovative, offering new insights through sector-specific comparisons across the GCC countries. It emphasizes the urgent need to cultivate renewable energy sources to protect the environment.

Research limitations/implications: The study excludes the transportation, manufacturing, and agriculture sectors, although these also significantly contribute to CO₂ emissions. The study suggests the need for targeted policies to mitigate emissions and promote sustainable development in the GCC countries.

Keywords: Liquidity, CO₂ Emission, Gas, Economic Growth, GCC, Cement, Oil.

JEL classification: C23, Q56, O13, Q01

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الملخص

انبعاثات ثاني أكسيد الكربون والنمو الاقتصادي في صناعات النفط والغاز والأسمت بدول الخليج: تحليل الانحدار الذاتي الموزع للفترات المتباطئة باستخدام بيانات السلاسل الزمنية المقطعية لتحقيق التنمية المستدامة

سارة الهاشمي

فاطمة المقبالي

نيتو كواترا

جامعة التكنولوجيا والعلوم التطبيقية، سلطنة عمان

هدف الدراسة: تهدف الدراسة إلى دراسة العلاقة بين انبعاثات ثاني أكسيد الكربون، والتنمية الاقتصادية في دول مجلس التعاون الخليجي، وتقارن بين مساهمة قطاعات النفط، والغاز، والأسمت في انبعاثات ثاني أكسيد الكربون في كل دولة من دول مجلس التعاون الخليجي. تصميم/ منهجية/ طريقة الدراسة: يتبع البحث التصميم الوصفي ويستخدم أساليب معيئة لتحليل البيانات، من مثل: OLS, POLS, ARDL.

عينة الدراسة وبياناتها: استخدمت الدراسة بيانات ثانوية من عام 1981 إلى 2021 لانبعاثات ثاني أكسيد الكربون ومعدلات نمو الناتج المحلي الإجمالي، ومن عام 1985 إلى 2022 للمساهمات المحددة لقطاعات النفط والغاز والأسمت.

نتائج الدراسة: توصلت الدراسة إلى وجود علاقة طويلة المدى بين انبعاثات ثاني أكسيد الكربون ومعدل نمو الناتج المحلي الإجمالي في دول مجلس التعاون الخليجي. ومع ذلك لا يظهر النمو الاقتصادي تأثيراً كبيراً على انبعاثات ثاني أكسيد الكربون على المدى القصير. إضافة إلى ذلك، يعد قطاع النفط المساهم الرئيسي في انبعاثات ثاني أكسيد الكربون في عُمان والكويت والمملكة العربية السعودية وقطر، في حين أنّ قطاع الأسمت يعد عاملاً بارزاً لانبعاثات ثاني أكسيد الكربون في الإمارات. كما أن انبعاثات ثاني أكسيد الكربون في البحرين تتأثر تأثراً كبيراً بقطاع الغاز.

أصالة الدراسة: تعد الدراسة نموذجاً جديداً عن طريق المقارنات القطاعية وتطورها ومدى تأثيرها على الانبعاثات الكربونية بين دول الخليج. ويبرز الحاجة الملحة لتطوير مصادر الطاقة المتجددة لحماية البيئة. حدود الدراسة وتطبيقاتها: تستثني الدراسة قطاعات مثل النقل والصناعات التحويلية والزراعة، التي تساهم أيضاً مساهمة كبيرة في انبعاثات ثاني أكسيد الكربون في دول مجلس التعاون الخليجي. وتشير الدراسة إلى الحاجة إلى سياسات مستهدفة للتقليل من الانبعاثات وتعزيز التنمية المستدامة في دول مجلس التعاون الخليجي.

الكلمات المفتاحية: انبعاثات ثاني أكسيد الكربون، النمو الاقتصادي، دول مجلس التعاون الخليجي، الأسمت، النفط، الغاز.

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Introduction

The Gulf Cooperation Council (GCC) region has long been a global leader in gas and oil productions, playing a crucial role in the world's energy landscape. However, this prominence in energy production is accompanied by significant carbon dioxide (CO₂) emissions stemming from the extraction, processing, and utilization of gas and oil resources. According to Zmami and Ben-Salha (2020), a key pillar for achieving sustainable development goals is closely tied to environmental sustainability. Duneja et al. (2024) projected a 30% growth in urban populations across the Middle East by 2030. Al-Badi and AlMubarak (2019) proposed that population growth in the GCC countries would boost energy demand, increasing CO₂ emissions. Measures such as renewable energy, efficiency, demand management, and fuel reforms are key to mitigating this adverse effect. Duneja et al. (2024) projected a 30% increase in urban populations across the Middle East by 2030, which aligns with Al-Badi and AlMubarak's (2019) assertion. CO₂ emissions from the gas and oil sectors remain a critical concern due to their contributions to climate change and environmental degradation. Al-Maamary et al. (2016) found that the rapid developments of GCC states have led to increased energy consumption and environmental pollution, affecting humans, water, and marine life. While there have been efforts to adopt renewable energy, most countries are still lagging behind in implementing sustainable energy solutions.

The GCC countries face unique challenges in balancing economic development through energy production with the urgent need to reduce CO₂ emissions to mitigate climate impacts. Recent data on the average energy consumptions of the GCC countries reveal increasing trends in energy usage and CO₂ emissions. This has led to an investigation into the combined impact of gross domestic product (GDP) and energy consumption (including gas, oil, and cement) on CO₂ emissions, which are critical concerns due to their contributions to climate change and environmental degradation.

Literature Review

Elgendy (2011) highlights that the high per capita energy consumption and carbon emissions in GCC countries are primarily due to water scarcity, necessitating energy-intensive desalination processes, especially in Saudi Arabia and the United Arab Emirates (UAE), which rely on fossil fuels. Zmami and Ben-Salha (2020) found that energy consumption and foreign direct investment (FDI) con-

tribute to environmental degradation in the GCC countries, whereas urbanization positively impacts environmental conditions. Magazzino (2016) identified long-term relationships between real GDP, CO₂ emissions, and energy usage in Oman, Kuwait, and Qatar, but not in Saudi Arabia.

Gorus and Aydin (2019) noted that energy conservation policies do not affect short-term economic growth but have long-term implications for CO₂ emissions in oil-rich countries in the Middle East and North Africa (MENA). Al-Mulali and Tang (2013) found energy consumption to be a consistent driver of CO₂ emissions in Oman and the UAE, with GDP growth showing mixed correlations. FDI inflows increased emissions in Bahrain but mitigated them in Oman, Qatar, and Saudi Arabia. Ozcan (2013) tested the environmental Kuznets curve (EKC) hypothesis in 12 Middle Eastern countries, confirming it in three and observing a U-shaped pattern for six.

Bouznit and Pablo-Romero (2016) confirmed the EKC hypothesis for Algeria, showing an increase in emissions with economic growth, which remained high at higher income levels. Salahuddin and Gow (2014) found energy use to be the primary driving factor of environmental degradation in the GCC countries. Bekhet et al. (2017) reported minimal long-term impacts of energy consumption, GDP, and financial development on CO₂ emissions, although their short-term impacts were significant in Saudi Arabia and Kuwait. Abdallah and Abugamos (2017) and Mahmood et al. (2020) identified urbanization as a key driver of emissions in the MENA region, correlating with increased economic activity and income levels.

Saidi and Hammami (2015) found that economic growth and energy consumption positively correlated with CO₂ emissions. Alsamara et al. (2018) confirmed that energy use and GDP per capita exacerbate environmental degradation, while financial development mitigates it. Salahuddin et al. (2015) observed that CO₂ emissions increase with economic growth and electricity consumption but decrease with financial development.

Antonakakis et al. (2017) showed a bidirectional relationship between energy use and economic growth, complicating policies for sustainable development in their research in 106 countries over the period 1971–2011. Acaravci and Ozturk (2010) found long-term links between CO₂ emissions, energy use, and economic growth in several European countries, supporting the EKC hypothesis in Denmark and Italy. Azam et al. (2016) found that CO₂ emissions negatively impacted economic growth in some countries, whereas trade and human capital had positive effects. Acheampong (2018) reported that energy consumption boosts economic growth in sub-Saharan Africa but has a negative impact on economic

growth in the regions of Middle East and North Africa (MENA), Asia Pacific, and Caribbean Latin America. Asif et al. (2015) linked urbanization in the GCC countries to increased CO₂ emissions, GDP, and energy consumption. Mahmood et al. (2022) revealed that economic growth and oil price fluctuations significantly affect CO₂ emissions in the GCC, with urbanization further exacerbating the issue. Al-Mulali and Tang (2013) found that in the GCC countries, FDI inflows had a limited impact on CO₂ emissions.

The aim of this study was to provide a comprehensive analysis of CO₂ emissions and GDP growth in the GCC countries, focusing on key sectors, such as oil, gas, and cement. By examining short- and long-term trends, the study provides valuable insights for policymakers on mitigating environmental degradation through investments in clean energy technologies and diversifying energy use. It addresses gaps in the literature by analyzing the interplay between economic growth, energy consumption, and CO₂ emissions, providing actionable recommendations for sustainable development.

Objectives of the Study

1. To investigate the long-term cointegration of CO₂ emission and GDP growth rate (GDPGR) across the GCC countries.
2. To examine how economic activities related to the gas, cement, and oil sectors contribute to CO₂ emissions across the GCC region.
3. To investigate and compare the impacts of economic activities related to the oil, gas, and cement sectors on CO₂ emissions across the GCC countries.

Hypotheses of the Study

H1: Changes in GDPGR have a statistically significant relationship with changes in CO₂ emission growth rate over time.

H2: Economic activities in the gas, oil, and cement sectors have statistically significant impacts on CO₂ emissions in the GCC countries.

H3: The effects of the economic activities in the oil, gas, and cement sectors on CO₂ emissions differ significantly across the GCC countries.

Data and Methodology

Annual data regarding CO₂ emission and GDPGR for the period 1981–2021 and pertaining to annual CO₂ emissions and CO₂ emissions from gas, cement, and

oil for the period 1985–2022 were acquired from the World Development Indicators and Our World in Data databases for all GCC countries. In this study, CO₂ emission growth rates, GDPGR, and annual CO₂ emissions (in metric tons) were the dependent variables, and annual CO₂ emission from gas, cement, and oil (in metric tons) were the independent variables. For each study objective, a different methodology was followed. The estimation of the model proceeded as follows:

- i) Three cross-sectional dependence (CD) tests were conducted to assess whether it exists across the panel of variables. These tests are crucial for determining whether observations from different entities exhibit correlation, which can stem from common factors, spatial effects, or shared characteristics. The potential CD can be attributed to factors such as geographic proximity and the heightened economic and financial interconnections among GCC countries. The three CD tests applied were the Pesaran (2004) CD test, Pesaran and Shin (1999) scaled lagrange multiplier (LM) test, and Breusch–Pagan LM test. These tests were applied to all variables included in the analysis to evaluate and verify the presence or absence of CD among the data (Pesaran, 2004).
- ii) On the basis of the presence of CD in (i), we used panel unit root tests to determine the order of integration. However, conventional unit root tests may not be suitable in this scenario because of CD. Hence, we employed second-generation methods, the Hadri and Fisher-type tests (Fisher-ADF and Fisher-PP) to determine the stationarity level. Heterogeneous tests are more flexible and account for potential differences in unit root behavior across entities but may require more computational effort and data (Choi, 2001).
- iii) Pesaran and Shin (1999) introduced the panel autoregressive distributed lag (ARDL) model or pooled mean group (PMG) technique for analyzing non-stationary dynamic panels. Panel ARDL models are used to examine the long-term relationships between variables in panel or longitudinal data while considering both individual-specific effects and time-series dynamics. Essentially, the ARDL model assumes that the variables are cointegrated, indicating that they have a long-term equilibrium relationship that persists over time. Cointegration suggests that despite short-term fluctuations in individual variables, they tend to move together in the long run owing to some underlying economic or theoretical connection. The mathematical expression of the panel ARDL model can be formulated as follows:

$$CO_{2it} = \beta_0 + \beta_1 GDP_{i,t-1} + \dots + \beta_{kxi,t-k} + \alpha_i + \epsilon_{it}, \quad (1)$$

where

- CO_{2it} represents CO_2 emission growth rates as the dependent variable for unit i at time t ;
- GDP_{it} is the independent variable for unit i at time t ;
- $0, 1, \dots, \beta_0, \beta_1, \dots, \beta k$ are the coefficients to be estimated;
- α_i represents individual-specific effects (fixed effects or random effects);
- ϵ_{it} is the error term;
- k represents the lag length of the independent variable; and
- $x_{i,t-k}$ represents a vector of explanatory (independent) variables that affect CO_2 emissions (CO_{2it}) other than lagged GDP.

(i) We used six dummy variables in our panel data (1985–2022) to control country-specific effects, enhancing model accuracy by accounting for differences in economic, policy, and environmental factors (Baltagi, 2005). (ii) We ran pooled ordinary least squares (POLS), which treats all panel units as a single sample and estimates a single regression model without accounting for individual-specific effects or time-series dynamics. (iii) Regardless of whether POLS was appropriate or not, we conducted the Breusch–Pagan test. By conducting the test and interpreting its results, we determined whether the POLS regression model was appropriate or if adjustments were needed to account for heteroscedasticity in the residuals. A significant result indicated that POLS was not appropriate. (iv) As suggested, we used a random-effects model (REM; one-way effect) with the Breusch–Pagan (BP) test. (v) The REM model was selected on the basis of the following criteria: REM assumes cross-sectional and time effects, which are used to estimate and understand the systematic difference in the given variables across countries. These effects are common across all entities (countries) and correlated with the independent variables, or a time-related trend may be affecting the relationship. This model incorporates a combined intercept, which results from merging the time series and cross-sectional components. In addition, it includes an individual intercept for each country, representing a unique and random characteristic of the first-unit observation. (vi) The Hausman test determines the appropriate estimation model between the REM and fixed-effect model (FEM). If the result supports H_0 , REM should be chosen ($p > 0.05$); otherwise, FEM should be chosen.

The ordinary least squares model has been employed for each country to estimate similarities in the impacts of the gas, oil, and cement sectors on CO₂ emissions specific to that country. This approach was used to assess the relationships between these sectoral activities and CO₂ emissions in each country, allowing for comparisons regarding the influences of gas, oil, and cement on the environmental outcomes across the GCC region.

Empirical Analysis

Step 1: Cross-Sectional Dependence Test

Table 1 represents the residual CD in the panel data. The mathematical model for CD can be written as follows:

$$CO_{2it} = \alpha + \beta GDP_{pit} + \lambda_i + \epsilon_{it} \quad (2)$$

where CO_{2it} is the dependent variable for entity *i* at time *t*; α is the overall intercept or constant term; β is the coefficient representing the effect of the independent variable; GDP_{it} is the independent variables for entity *i* at time *t*; λ_i is the entity-specific unobserved effect (common correlated effect); and ϵ_{it} is the error term, which may be correlated across entities.

Table 1
Residual Cross-Sectional Dependence (Period 1981–2021 for GCC)

Dependent variable: CO ₂ emission, Independent variable: GDP growth rate			
Test	<i>t</i> -statistic	<i>p</i> -value	Cross-sectional Dependence
Breusch–Pagan LM	42.23	0.002**	Present
Pesaran CD Test	3.046	0.002**	Present
Pesaran scaled LM	4.97	< 0.001***	Present
Model Information			
Periods included		41	
Cross-sections		6	
Total number of observations		213	

****p* < 0.001, ***p* < 0.01, **p* < 0.05

Table 1 presents the outcomes of three tests for CD, namely the Pesaran (2004) CD test, Pesaran (2004) scaled LM test, and Breusch–Pagan LM test. The null hypothesis for all three tests was the absence of CD. The results indicate significant interdependence among all variables across the countries. At the 5% significance level, the null hypothesis of cross-sectional independence is rejected, suggesting CD in CO₂ emissions, which might be due to the social, economic, and financial ties among the GCC countries.

Step 2: Panel Unit Root Test

Given the presence of CD, it is necessary to apply second-generation panel unit root tests for panel ARDL modeling. Table 2 summarizes the results of the second-generation panel unit root tests and their respective hypotheses.

Table 2
Second-Generation Panel Unit Root Summary (*p*-values)

Model	Fisher-PP	Fisher-ADF	Hardi Test
GDPGR I(0)	< 0.001 (S)***	< 0.001 (S)***	0.021 (S)*
DGDPGR I(1)	< 0.001 (S)***	< 0.001 (S)***	0.43 (NS)
C02EGR I(0)	< 0.001 (S)***	< 0.001 (S)***	0.41 (NS)
DC02EGR I(1)	< 0.001 (S)***	< 0.001 (S)***	0.10 (NS)

Model Information

Observations	216
Cross sections	6
Lag	1

****p* < 0.001, ***p* < 0.01, **p* < 0.05; NS: non-stationary, S: stationary

The findings indicate that the variables are non-stationary, except in the Hadri test, which supports the stationarity of GDPGR at the level I(0). However, all other tests suggested that the variables were non-stationary. The Fisher-type tests (Fisher-ADF and Fisher-PP) both rejected the null hypothesis of a unit root, indicating the absence of a unit root in the data. In conclusion, considering the majority decision based on the tests, we proceeded with the panel PMG/ARDL model to examine the cointegration among the variables across the GCC countries.

Step 3: Panel ARDL Model

The long-term impact of the GDPGR on CO₂ growth rate was estimated using the PMG/ARDL approach to test H1, which states that changes in GDPGR have

a statistically significant relationship with changes in CO₂ emissions growth rate over time. The estimation results are displayed in Table 3.

Table 3
Panel PMG/ARDL Model Summary (Short- and Long-Term Equilibrium) for the Period 1982–2021

Dependent Variable: $D(CO_2EGR)$			
Variable	Coefficient	<i>p</i> -value	Conclusion
Long-run Equation			
GDPGR	0.399	< 0.001***	H1 supported, cointegration exists
Short-run Equation			
COINTEQ01	-1.171	< 0.001***	H1 supported, cointegration exists
C	3.4492	< 0.001***	-
Model Information			
Observations	207		
Model Selection Method	AIC		
Selected Model	(ARDL 1,1)		

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$

In Table 3, the findings indicate a long-term relationship between GDPGR and CO₂ER, as the *p*-value is < 0.05, which accepts the alternate hypothesis H1. The coefficient value shows that a 1% increase in GDP leads to an approximately 39.9% increase in CO₂ emissions, which is relatively high across the GCC countries in the long term. In addition, the statistically significant short-term outcome supports H1, indicating that the relationship occurring by random chance is unlikely. “COINTEQ01”(-1.1715) is negative and suggests that a negative short-term relationship exists between the GDPGR and CO₂ER, which would imply that as GDPGR increases, CO₂ER tends to decrease over the short term.

Table 4 presents the individual ARDL cointegration models for each country to estimate the presence of a long-term relationship between CO₂ emission rates and GDPGRs. Here, H1 is the presence of integration in the short term.

Table 4
Individual ARDL Cointegration

Dependent Variable: $D(CO_2EGR)$, Independent variable: $D(GDPGR)$				
Country	Variable	Coefficient	p-value	CO₂ Co-Integration with GDP
Oman	COINTEQ01	-1.076	< 0.001***	Not co-integrated
	D(GDPGR)	-0.221	0.213	
	C	5.374	0.263	
Kuwait	COINTEQ01	-1.009	< 0.001***	Not co-integrated
	D(GDPGR)	-0.217	0.09	
	C	1.500	0.675	
Saudi	COINTEQ01	-0.998	< 0.001***	Not co-integrated
	D(GDPGR)	0.089**	0.109	
	C	3.067	0.372	
UAE	COINTEQ01	-1.199	< 0.001***	Not co-integrated
	D(GDPGR)	0.143**	0.101	
	C	4.765	0.211	
Qatar	COINTEQ01	-1.464	< 0.001***	Not co-integrated
	D(GDPGR)	-0.119	0.0974	
	C	2.137	0.6206	
Bahrain	COINTEQ01	-1.284	< 0.001***	Not co-integrated
	D(GDPGR)	-0.079	0.725	
	C	3.855	0.439	

Model Information

Lag	1
Observations	207
Model Selection	AIC
Selected Model	(ARDL 1,1)

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$

The findings suggest that GDPGR had no short-term impact on the CO₂ emission rate in each country, as indicated by the p -values > 0.05 . In addition, the coefficient values are negative for all countries except the UAE and Saudi Arabia. Thus, H1, which states that there is cointegration between GDPGR and CO₂ emission rate in the short run, is accepted for all countries.

To examine how the economic activities related to the gas, cement, and oil sectors contribute to the CO₂ emissions across the GCC region, the following steps were implemented:

Step 1: Dummy variables Doman, DKuwait, DSaudi, DQatar, DUAE, and DBahrain were created.

Step 2: The results of the POLS regression used to test H2, which posits that economic activities in the gas, oil, and cement sectors have statistically significant impacts on CO₂ emissions in GCC countries, are presented in Table 5.

Table 5
Panel OLS for the Period 1985–2022

Dependent Variable ACO2 (Annual CO ₂) Emission (mt)			
Variable	Coefficient	p -value	Conclusion
ACO ₂ Cement	-0.37	< 0.001***	H2 supported
ACO ₂ Gas	-0.99	< 0.001***	H2 supported
ACO ₂ Oil	0.96	< 0.001***	H2 supported
C	-141	0.475	
Model Information			
R^2	0.99		
Prob(F -statistics)	< 0.001***		
Periods	38		
Balanced observations	228		

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$

Table 5 presents the results of the POLS analysis. The support of H2 indicates a significant impact of the economic activities in the oil, gas, and cement sectors on the overall CO₂ emissions across the GCC countries. This significance is further supported by the statistically significant coefficients for ACO₂Cement,

ACO₂Gas, and ACO₂Oil, all with *p*-values < 0.05, as indicated in the table. The adjusted *R*² value of 0.99 suggests that approximately 99% of the variation in the dependent variable (ACO₂Emission) is explained by the independent variables considered in the model. Adjusted *R*² is a crucial measure, as it accounts for the number of variables in the model, allowing for a more reliable assessment of the goodness of fit of the model. Moreover, the overall *p*-value of < 0.001 (< 0.05) signifies that the overall model is statistically significant. Consequently, we accept H2, indicating a substantial effect of the gas, oil, and cement sectors on the overall CO₂ emissions across the GCC region.

Step 3: The results of the Breusch-Pagan test used to check the appropriateness of a POLS regression model are presented in Table 6.

Table 6
Lagrange Multiplier (Breusch–Pagan) Test for Random Effects:
Cross-Section, Time, and Both Dimensions

Cross Section	Time Hypothesis	Both
377.67 (<i>p</i> < 0.001)***	1.592 (<i>p</i> = 0.216)	379.20 (<i>p</i> < 0.001)***

****p* < 0.001, ***p* < 0.01, **p* < 0.05

Table 6 indicates that the cross-sectional effect has a significant *p*-value < 0.001, while the time effect is not significant, with a *p*-value of 0.2162. This suggests that the one-way REM is more suitable. In addition, as the total *p*-value is < 0.05, we reject the null hypothesis (H0) and opt for the REM/FEM as the appropriate modeling approach. POLS are deemed inappropriate in this context.

Step 4: The results of the Breusch–Pagan test performed to check the appropriateness of a POLS regression model are presented in Table 7. The mathematical equation of the REM model is as follows:

$$\begin{aligned}
 REM: ACO_2Emission = & C(-0.3810) \times ACO_2Cement + C(-0.964) \times ACO_2Gas \\
 & + C(0.952) \times ACO_2Oil + C(-15363) + [CX=R]
 \end{aligned}
 \tag{3}$$

Table 7
Panel EGLS REM Model (One-Way Effect) for the Period 1985–2022

Dependent Variable: ACO₂Emission Swamy and Arora Estimators of Component Variance		
Variable	Coefficient	<i>p</i>-value
ACO ₂ Cement	-0.381	< 0.001***
ACO ₂ Gas	-0.964	< 0.001***
ACO ₂ Oil	0.952	< 0.001***
C	-15364	0.045*
Model Information		
Observations	228	
Adjusted <i>R</i> ²	0.998	
Prob (<i>F</i> stat)	< 0.001***	

****p* < 0.001, ***p* < 0.01, **p* < 0.05

The results of the REM are displayed in Table 7. Here, the *p*-value is < 0.05, which means that a significant relationship exists between the CO₂ emission rate and the contribution of the economic activities related to the gas, oil, and cement sectors across the GCC countries. Moreover, the overall *p*-value is less than the level of significance, which further proves the significant impacts of the CO₂ emissions from the oil, gas, and cement sectors on the overall CO₂ emission in the GCC countries. It is evident that the *R*² value of 0.9987 indicates that 99.8% of the ACO₂ emission growth rate can be explained by the independent variables: (ACO₂Cement, ACO₂Gas, and ACO₂Oil). The overall result is significant, thus indicating that all CO₂ emissions from the gas, oil, and cement sectors had a significant effect on the CO₂ emission across the GCC countries. The coefficients of the independent variables (gas, oil, and cement sectors) for the GCC countries were determined by Equation 4. The equation shows that the gas, oil, and cement sectors had noticeable effects on the CO₂ emission rate. The coefficient of the gas and cement sectors is negative, while that of the oil sector was positive, which indicates that most 95.2% of the CO₂ emissions were from the oil sector. By contrast, the gas and cement sectors showed a negative relationship with the CO₂ emission across the GCC countries.

Table 8
Results of the Individual Intercept (C)-Specific Intercept

Country	Effect
Oman	-1750
Saudi Arabia	1,611,200
Bahrain	17,090
UAE	-22,946
Qatar	-5,229
Kuwait	12,475

Table 8 presents the individual intercept of all the countries. These differences could be due to various factors, such as economic structure, regulatory policies, cultural aspects, and geographic features specific to each country.

Step 5: The Hausman test was applied to assess whether the REM was appropriate or if it was more suitable to proceed with the FEM. $H(0)$ states that REM is better than FEM.

Table 9
Correlated Random-Effect Hausman Test

Dependent Variable: ACO ₂ Emission			
Independent Variable	Coefficient	Prob	Conclusion
ACO ₂ Cement	-0.381	0.793	REM preferred
ACO ₂ Gas	-0.963	0.088	REM preferred
ACO ₂ Oil	0.951	0.176	REM preferred
Overall	0.35	0.35	REM preferred

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$

Table 9 presents the results of the Hausman test, which indicate that the REM is more appropriate than the FEM on the basis of the p -value > 0.05 . Accepting the null hypothesis in this context means that there is no systematic difference between the coefficients estimated in the REM and FEM, which suggests that the REM is the preferred model for the data. In addition, the individual p -values for all independent variables are significant, indicating that these variables had statistically significant impacts on the dependent variable in the REM.

Objective 3: Table 10 presents a summary of the ordinary least squares models conducted for each GCC country, with annual CO₂ emissions as the dependent variable and CO₂ emissions from each sector (oil, gas, and cement sectors) as independent variables. This analysis was performed to examine the relationship between the sectoral emissions and the CO₂ emissions in each country in the GCC region.

Table 10
Summary of the Ordinary Least Squares of the GCC Countries
for the Period 1985–2022

Dependent Variable: CO ₂ Emissions							
Country	Variable	Coefficient	<i>p</i> -value	<i>R</i> ²	Adjusted <i>R</i> ²	<i>F</i> -stat (<i>p</i> -value Overall)	Conclusion H3
Oman	CO ₂ Cement	-0.542	0.7315	0.998	0.998	< 0.001***	Supported
	CO ₂ Gas	1.087	< 0.001***				
	CO ₂ Oil	1.123	< 0.001***				
	C	2185	< 0.001***				
Kuwait	CO ₂ Cement	0.634	0.0412	0.999	0.999	< 0.001***	Supported
	CO ₂ Gas	0.934	< 0.001***				
	CO ₂ Oil	1.055	< 0.001***				
	C	1148	0.001**				
Saudi	CO ₂ Cement	0.493	< 0.001***	0.999	0.999	< 0.001***	Supported
	CO ₂ Gas	0.977	< 0.001***				
	CO ₂ Oil	1.008	< 0.001***				
	C	5683	< 0.001***				
UAE	CO ₂ Cement	1.155	0.028*	0.999	0.999	< 0.001***	Supported
	CO ₂ Gas	0.969	< 0.001***				
	CO ₂ Oil	1.043	< 0.001***				
	C	1062	0.179				
Qatar	CO ₂ Cement	1.087	0.019*	0.998	0.998	< 0.001***	Supported
	CO ₂ Gas	0.954	< 0.001***				
	CO ₂ Oil	1.296	< 0.001***				
	C	1029	0.070				

Cont. Table 10
Summary of the Ordinary Least Squares of the GCC Countries
for the Period 1985–2022

Dependent Variable: CO ₂ Emissions							
Country	Variable	Coefficient	p-value	R ²	Adjusted R ²	F-stat (p-value Overall)	Conclusion H3
Bahrain	CO ₂ Cement	0.811	< 0.001***			< 0.001***	Supported
	CO ₂ Gas	1.015	< 0.001***	0.999	0.999		
	CO ₂ Oil	0.981	< 0.001***				
	C	-118,353.1	< 0.001***				

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$

The findings from the ordinary least squares models indicate that the oil, gas, and cement sectors had significant impacts on the CO₂ emissions in each GCC country. This conclusion is based on the p -values < 0.05 , which leads to the acceptance of the alternate hypothesis in each country. From the comparison of the impacts of the independent variables based on their coefficient values, it is evident that the impacts of the various sectors differ between the GCC countries. Specifically, Oman and Saudi Arabia showed the highest impact from the oil sector (coefficient value of 1.12), indicating that oil-related activities have a significant influence on the CO₂ emissions in these countries. Kuwait, Qatar, and the UAE are mostly impacted by the cement sector, which suggests that the activities related to cement production contribute significantly to the CO₂ emissions in these countries. Bahrain’s CO₂ emissions are notably impacted by the gas sector, indicating that gas-related activities play a major role in influencing CO₂ emissions in Bahrain.

Despite these differences, all three sectors (the oil, gas, and cement sectors) have p -values < 0.05 across all GCC countries, which indicates that they all had a significant impact the CO₂ emissions in the respective countries. Hence, overall, H3, which states that the effects of the economic activities of the oil, gas, and cement sectors on CO₂ emissions differ significantly across the GCC countries, is accepted. Equations (1)–(6) show the relationship between the CO₂ emissions and the economic activities in the oil, gas, and cement sectors for each GCC countries.

The coefficients represent the impact of each sector on CO₂ emissions in terms of the amount of CO₂ emission produced per unit of activity in that sector.

$$\text{Equation 1: } \text{ACO}_2(\text{Oman}) = -0.541710956394 \times \text{ACO}_2\text{Cement} + 1.08662171532 \times \text{ACO}_2\text{Gas} + 1.12330322306 \times \text{ACO}_2\text{Oil} + 2185193.81301$$

$$\text{Equation 2: } \text{ACO}_2(\text{UAE}) = 1.04469933702 \times \text{cement} + 0.968582532386 \times \text{gas} + 1.15285903236 \times \text{oil} + 1061661.94363$$

$$\text{Equation 3: } \text{ACO}_2(\text{Saudi}) = 1.04925365768 \times \text{annual_coa_emissions_from_cement} + 0.976923205677 \times \text{annual_coa_emissions_from_gas} + 1.00812139315 \times \text{annual_coa_emissions_from_oil} + 5683248.78513$$

$$\text{Equation 4: } \text{ACO}_2(\text{Qatar}) = 2.18675574874 \times \text{cement} + 0.95427606212 \times \text{gas} + 1.29556223532 \times \text{oil} + 1029164.00733$$

$$\text{Equation 5: } \text{ACO}_2(\text{Bahrain}) = 0.811109973063 \times \text{cement} + 1.01453375985 \times \text{gas} + 0.980627223518 \times \text{oil} - 118353.070594$$

$$\text{Equation 6: } \text{ACO}_2(\text{Kuwait}) = 0.63437534243 \times \text{CO}_2\text{cement} + 0.933739642068 \times \text{CO}_2\text{gas} + 1.0550724903 \times \text{CO}_2\text{oil} + 1147846.79227$$

Findings and Discussion

CD in CO₂ levels has been observed in the GCC countries, attributed to their economic, financial, and social interconnectedness. Research indicates long-term cointegration between economic growth rates and CO₂ emissions across the GCC countries. The findings of this study align with those of Magazzino (2016), Saidi and Hammami (2015), and Zmami and Ben-Salha (2020). A significant long-term relationship exists between CO₂ emission rates and GDPGRs in both the short and long terms, as evidenced by the panel ARDL approach. However, no short-term cointegration exists between the GDP and CO₂ emissions within individual countries. This study further contributes to this area of research by providing a sector-specific comparative analysis of GDPGRs and CO₂ emissions. Economic activities related to oil, gas, and cement production significantly impact CO₂ emissions. In particular, the influence of the activities in the oil sector is the most substantial across the GCC countries, surpassing those of the gas and cement sectors. An additional analysis revealed that while the oil, gas, and cement sectors collectively made a significant contribution to CO₂ emissions, Oman, Qatar, Kuwait, and Saudi Arabia are predominantly affected by economic activities in the oil sector. In the UAE, CO₂ emissions are notably influenced by the cement sector.

In Bahrain, the gas sector had the highest impact on CO₂ emission rates. The support for H1, which states that changes in GDPGR have a consistent relationship with changes in CO₂ emission growth rate, can be attributed to the evidence from the panel ARDL approach, which suggests a significant long-term relationship between economic growth and CO₂ emissions. This finding supports the hypothesis, as the data show that economic growth rates influence CO₂ emissions over time. H2, which suggests that the economic activities in the gas, oil, and cement sectors have a substantial impact on the CO₂ emissions in the GCC countries, is accepted. The sector-specific analysis revealed that these activities are substantial drivers of CO₂ emissions. H3, which states that the effects of the economic activities of the oil, gas, and cement sectors on CO₂ emissions differ significantly across the GCC countries, is accepted because the study reveals notable differences across the GCC countries. While the oil sector was the primary contributor in most GCC countries, sectors such as the cement sector in the UAE and the gas sector in Bahrain showed different impacts on CO₂ emissions, indicating that the relationship is not uniform across the region. This variation supports the acceptance of H3.

Conclusion

CO₂ emissions and GDPGR have long-term cointegration across GCC countries, with the oil sector being the primary contributor to CO₂ emissions. Therefore, the government should reduce CO₂ emissions while sustaining economic development. There should be a push toward diversifying energy sources. The government should invest in renewable energy sources, such as solar and wind, to reduce dependency on oil and alleviate environmental stress. The results of this study indicate support for the rejection of Hypotheses 1, 2, and 3. H1 is supported, as the panel ARDL approach shows a significant long-term relationship between GDP growth and CO₂ emissions. H2 is supported because the oil, gas, and cement sectors significantly influenced CO₂ emissions, especially the oil sector in most GCC countries. H3 is accepted owing to the varying sectoral impacts across the GCC, with oil being dominant in most countries; cement, in the UAE; and gas, in Bahrain, suggesting that apart from the oil sector, other sectors, such as tourism, can help mitigate environmental degradation while creating new opportunities for sustainable growth and reducing carbon intensity. This highlights the critical importance of formulating policies that encourage investors to diversify their investments into energy-efficient sectors and promote the use of renewable energy sources.

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Neetu Kwatra a faculty member at UTAS-Al-Mussanah, is renowned for her work in teaching and research. She has expertise in human resource development and labor legislation, with 17 published papers and five international conference presentations in business strategies, human resource management, and economics. Passionate about economics and sustainable development, she has collaborated on projects funded by the Ministry of Higher Education, Research and Innovation. She won a best paper award at an international conference in 2022 and continues to submit proposals to key ministries. (neetu.kwatra@utas.edu.om)

Fatema Almaqbali is a Lecturer in the Business College Department at the University of Technology and Applied Sciences in Oman. Previously, she worked as an instructor at Saham Vocational College. She holds an MBA and has conducted extensive research in entrepreneurship and marketing. Her research interests primarily focus on labor market integration, entrepreneurship, and the development of marketing strategies. She has contributed to numerous studies aimed at understanding business dynamics and fostering innovation within the entrepreneurial ecosystem. (Fatema.almaqbali@utas.edu.om)

Sarah Al-Hashemi is a Lecturer in Business Studies at the University of Technology and Applied Sciences, Oman. She holds an MBA and a bachelor's degree in human resource management. Her research interests include employment, entrepreneurship, and personal branding. (Sarahalhashmi25@gmail.com)

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