Exploring the relationship between economic diversification and energy-related CO_2 emissions in a petroleum-producing country

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Abstract

Purpose – This study aims to quantify sectoral energy and carbon intensity, revisit the validity of the Environmental Kuznets Curve (EKC) and explore the relationship between economic diversification and CO_2 emissions in Bahrain.

Design/methodology/approach – Three stages were followed to understand the linkages between sectoral economic growth, energy consumption and CO_2 emissions in Bahrain. Sectoral energy and carbon intensity were calculated, time series data trends were analyzed and two econometric models were built and analyzed using the autoregressive distributed lag method and time series data for the period 1980–2019.

Findings – The results of the analysis suggest that energy and carbon intensity in Bahrain's industrial sector is higher than those of its services and agricultural sectors. The EKC was found to be invalid for Bahrain, where economic growth is still coupled with CO_2 emissions. Whereas CO_2 emissions have increased with growth in the manufacturing, and real estate subsectors, the emissions have decreased with growth in the hospitability, transportation and communications subsectors. These results indicate that economic diversification, specifically of the services sector, is aligned with Bahrain's carbon neutrality target. However, less energy-intensive industries, such as recycling-based industries, are needed to counter the environmental impacts of economic growth.

Originality/value – The impacts of economic diversification on energy consumption and CO_2 emissions in the Gulf Cooperation Council petroleum countries have rarely been explored. Findings from this study contribute to informing economic and environment-related policymaking in Bahrain.

Keywords Climate change mitigation, Economic diversification, Energy intensity

Paper type Research paper

1. Introduction

Fossil fuels play a dominant role as sources of energy and income in the Gulf Cooperation Council (GCC) petroleum-producing countries. Most of the GCC countries have pledged to achieve net zero CO_2 emissions by 2060 or earlier, namely Bahrain, Saudi Arabia, Oman, Kuwait and the United Arab Emirates (UAE). However, transitioning to carbon neutrality

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will require a shift from a hydrocarbon-based economy to a sustainable circular carbon economy (Alsabbagh and Alnaser, 2022).

Several GCC countries have prioritized economic diversification to reduce their reliance on oil and gas revenues over the past decades. Bahrain initiated its economic diversification plans in the 1970s, with a focus on boosting its industrial sector. The service sector is also a focus area, as elaborated in Bahrain's Economic Vision 2030, which was launched in 2008 (Information and eGovernment Authority, 2021a). Given Bahrain's abundant fossil fuel resources, energy-intensive industries, notably those producing aluminum, steel and cement, began to operate and expand in the country. This approach to industrial development resulted in an energy-intensive economy (9.24 gigajoules [GJ] per US$1,000), compared with the global average and those of member countries of the Organization for Economic Cooperation and Development (OECD) and Middle Eastern countries (4.77, 3.84 and 6.48 GJ per US$1,000, respectively) (IEA, 2021b). Given Bahrain's almost complete reliance on fossil fuels, the consequent CO_2 emissions are relatively high. For instance, the per capita CO_2 emissions indicator for Bahrain is 19.9 tCO_2 per capita, which exceeds that of some of the GCC countries, notably Saudi Arabia and the UAE as well as Middle East countries (14.5, 18.2 and 7.2 tCO_2 per capita, respectively) (IEA, 2021b).

The scale and types of economic activities affect the environment (Polasky *et al.*, 2019). To reconcile the gap between Bahrain's current economic structure and its carbon neutrality target, it is necessary to examine the relationship between sectoral economic growth and CO_2 emissions in Bahrain. The Environmental Kuznets Curve (EKC) was therefore adopted in this study to display the relationship between economic growth and CO_2 emissions. According to the EKC hypothesis, economic growth negatively affects environmental quality until they are decoupled at a certain point, enabling economic growth to resume with improved environmental quality. However, the results of tests to confirm the validity of the EKC hypothesis in Bahrain proved inconclusive.

The aim of this study was to explore the relationship between growth within different economic sectors in Bahrain and associated CO_2 emissions. Its specific objectives were as follows:

- to examine the growth trends of sectoral contributions to the GDP, along with its energy consumption and CO_2 emissions;
- to determine sectoral energy intensities, that is, the amount of energy consumed to produce the GDP and consequent CO_2 emissions;
- to revalidate the EKC hypothesis for Bahrain; and
- to determine the relationship between economic diversification and CO_2 emissions.

This study contributes to the literature by advancing understanding of how economic diversification plans in a petroleum-producing country impact its climate change-related commitments. This topic remains underexplored in empirical studies conducted in GCC countries, with few studies having examined the linkages between sectoral economic growth and energy and carbon intensities. Uncovering these linkages between the economy and the environment is imperative to understand how previous and current economic initiatives influence the state of the environment, which is the first step toward mitigating CO_2 emissions (Alsabbagh and Alnaser, 2022, 2023). This understanding can inform efforts to achieve national energy efficiency, renewable energy targets and the global sustainable development goals (SDGs), specifically the seventh and thirteenth goals on energy and climate action, respectively. Importantly, the use of data collected from national authorities in the present study addresses existing data gaps in international databases and can be used in future studies.

This paper comprises five sections. Section 2 reviews the key literature on economic growth and climate change, and EKC in the GCC countries. Section 3 describes the study area and explains the methodology, followed by the results and discussion in Section 4. Section 5 offers conclusions and recommendations emerging from the findings.

2. Literature review

2.1 Economic growth and climate change

The relationship between the economy and the environment can be examined from three main aspects: inputs, processes and outputs. The environment provides raw materials and energy sources, which constitute the main inputs of economic activities. Because economic activities take place in the environment, they affect and are affected by it, with byproducts of waste and pollutants resulting from these activities (Polasky *et al.*, 2019). The relationship between economic growth and climate change is the same, as climate change is largely caused by human activities, which entail the consumption of fossil fuels to meet human needs, in addition to other activities such as industrial processes, agricultural production and waste generation. Accordingly, economic growth and climate change are "coupled," prompting calls by several scholars for economic degrowth to reduce CO_2 emissions (Sandberg *et al.*, 2019; Zafeiriou, Mallidis, *et al.*, 2018).

While the cause–effect relationship between economic activities and the quality of the environment prevailed for a long period, it began to diminish with the emergence of the sustainable development concept. Sustainable development can be understood as a developmental approach for meeting human needs in a socially accepted, economically feasible and environmentally friendly way. Economic growth is considered integral for improving environmental quality (Stern, 2018), which implies that the decoupling of economic growth and environmental quality is possible as shown in (Haberl *et al.*, 2020). However, findings indicate that the reduction in CO_2 emissions is limited. The EKC provides a theoretical interpretation for the decoupling of economic growth and environmental quality. Specifically, it posits that they remain coupled up to a certain point, after which decoupling occurs, wherein the economy continues to grow while environmental pollution decreases.

Several regulatory and technological options exist for CO_2 emissions reduction, which can be accomplished in two ways: by reducing emissions from the source and by enhancing emissions sinks. Both approaches are needed to achieve the carbon neutrality targets set by the GCC countries (Alsabbagh and Alnaser, 2022). Reducing CO_2 emissions at source entails adopting energy efficiency and renewable energy measures and technologies, while carbon sink enhancement entails initiatives such as afforestation and mangrove planation, along with carbon capture, use and storage technologies. Efforts to align economic activities and climate-related targets in the GCC countries involve "greening" existing industries, including energy and carbon-intensive industries such as the aluminum, cement and steel, as described in their updated nationally determined contributions reports. It is noteworthy that several constraints impede Bahrain's readiness for climate change mitigation, as suggested in the literature (Alsabbagh and Alnaser, 2023). An assessment based on 15 mitigation requirements revealed several weaknesses relating to climate change strategy, capacity building and stakeholders' awareness and education, indicating areas that require improvement to achieve carbon neutrality in Bahrain (Alsabbagh and Alnaser, 2023).

To measure progress made thus far toward reducing CO_2 emissions, several economic indicators can be used, such as energy and carbon intensity (for the entire economy, for a specific sector or industry, or for energy-intensive industries only), energy productivity (GDP per unit of energy consumed), the energy mix and the carbon footprint of specific sectors or industries (IEA, 2021b; International Atomic Energy Agency and United Nations, 2007). Many of these indicators have been calculated at the national level, for example, by the US Energy Information Administration in the USA, or at the regional level, for example, by Eurostat in Europe, or internationally through the International Energy Agency (IEA). Notably, such indicators are not readily available in the GCC countries either at the country or regional levels (through the statistical center for the GCC countries – GCC STAT).

2.2 Environmental Kuznets Curve

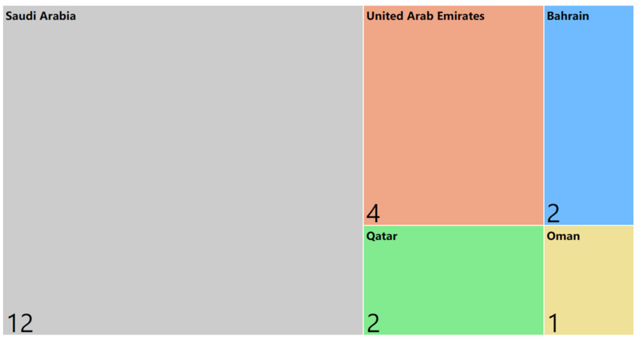
The validity of the EKC hypothesis is associated with several factors relating to the scale of the economy, types of activities and the technologies and natural resources used (Alaali and Naser, 2020; Stern, 2018). The validity of the EKC hypothesis has been tested using the GDP as a proxy for economic growth and CO_2 emissions as a proxy for environmental quality in several countries, either on a stand-alone basis or for a panel of countries. These studies can be categorized according to their geographical location, economic sectors examined, dependent variables and findings. The majority of studies have examined the validity of the EKC hypothesis in the context of panel of countries such as the European Union countries (Frodyma *et al.*, 2022) and Middle East and North Africa (MENA) countries (Ardakani and Seyedaliakbar, 2019). By contrast, some studies have focused on a single country, usually a developing country, such as India (Villanthenkodath *et al.*, 2021) and Indonesia (Prastiyo *et al.*, 2020). The body of literature on the EKC can also be categorized according to the economic sectors under investigation. A few studies have tackled a single sector, such as transportation (Alshehry and Belloumi, 2017) and construction (Zhang *et al.*, 2019) or multiple economic sectors (Prastiyo *et al.*, 2020). However, the majority of studies in this area have tackled economic growth proxied with GDP in general, with very few focusing on the value added by specific economic sectors. The dependent variables studied in relation to economic growth and climate change have also varied. To explain the relationship between CO_2 emissions and economic growth, several economic, demographic and other variables have been used, such as trade openness as in Aslam *et al.* (2021), energy consumption (Ardakani and Seyedaliakbar, 2019), population (Villanthenkodath *et al.*, 2021), research and development expenditure (Rahman *et al.*, 2022), the number of patents (Samargandi, 2017) and globalization (Aslam *et al.*, 2021). Findings emerging from the data analysis have also varied; some supported the EKC hypothesis, while others indicated its invalidity with several shapes being obtained, including a U-shape, inverted U-shape, N-shape or inverted N-shape (AlKhars *et al.*, 2022; Shahbaz and Sinha, 2019). A review of the literature reveals that these findings may be inconclusive, as the results of studies that have examined the validity of the EKC hypothesis may vary according to the time series data, independent variables and the method of data analysis used (Shahbaz and Sinha, 2019).

As with any theory, the EKC has been subjected to criticism, including questions raised on the possibility to decouple economic growth and environmental pollution. This critique has focused on the pollution haven hypothesis, wherein polluting activities, under free trade agreements, move from developed to developing countries characterized by labor availability and abundant natural resources, specifically fossil fuels. This movement allows for economic growth in developed countries, while the environmental pollution burden is borne by developing countries, resulting in the conclusion that the EKC hypothesis is valid for developed countries (Stern, 2018). Another challenge the validity of the EKC relates to is shifting of environmental problems as opposed to solving them. For instance, technological advances have helped to reduce air pollutants, such as sulfur and nitrogen oxides; however, they have also created other problems, such as emissions of $CO_{2,}$ and generated waste. To overcome this criticism, other approaches, such as decomposition and convergence analysis have been suggested, which focus on the relationship between economic growth and environmental pollution. However, these approaches are highly data intensive and require detailed data that are often unavailable in developing countries. Nonetheless, technological advancements offer opportunities for green economic growth (Haberl *et al.*, 2020), requiring fewer inputs and generating less waste, as in the circular economy in which recycled materials are substituted for raw materials, thus consuming fewer natural resources.

2.3 The validity of the Environmental Kuznets Curve hypothesis in the Gulf Cooperation Council countries

A search of the Scopus database revealed 21 empirical studies that have explored the validity of the EKC hypothesis in the GCC countries on individual country basis (Figure 1). The EKC hypothesis was tested in Qatar using the autoregressive distributed lag (ARDL) method and data on energy consumption, financial development and trade openness for the period 1980–2011 and found to be invalid (Mrabet and Alsamara, 2017). Another study found evidence of an N-shaped curve (Shannak and Contestabile, 2022), which suggests that Qatar is at a second turning point, wherein CO_2 emissions are continuing to increase concurrently with economic growth. Applying different time series data and analytical methods, four studies demonstrated the validity of the EKC hypothesis in the UAE (Charfeddine and Ben Khediri, 2016; Majumdar and Paris, 2022; Shahbaz *et al.*, 2014; Udemba, 2021). Various independent variables were used in these studies, including financial development, electricity consumption and the urbanization rate. In one study on Oman, time series data for the period 1984–2014 and the ARDL, fully modified ordinary least squares and dynamic ordinary least square methods were used to explore the relationship between export diversification, energy consumption and economic growth on the one hand, and CO_2 emissions and ecological footprints on the other hand (Saboori *et al.*, 2022). However, empirical studies to test the validity of the EKC hypothesis in Kuwait on a stand-alone basis are not evident in the literature.

The majority of studies (12) have empirically examined the validity of the EKC hypothesis in Saudi Arabia. Most of these studies addressed the economy as a whole, but two studies focused on specific economic sectors: transportation (Alshehry and Belloumi, 2017) and agriculture (Mahmood, 2022). Only one study, which explored the relationship between CO_2 emissions and sectoral economic growth (Samargandi, 2017), reported a positive relationship between the growth of emissions and that of industrial value added to the Saudi GDP. Thus, the results of testing the EKC hypothesis are inconclusive as it was



Source: Created by author using results from Scopus search

Figure 1. The number of Scopus-indexed, peer-reviewed studies on EKC in individual GCC countries

validated in some studies (Alsaedi *et al.*, 2022; Kahia *et al.*, 2021; Mahmood, 2022; Omri *et al.*, 2019) and rejected in others (Al-Torkistani *et al.*, 2016; Raggad, 2018).

Two studies have examined the validity of the EKC hypothesis in Bahrain on a stand-alone basis, and six studies have examined its validity within a group of countries (Table 1). One study applied the ARDL method using World Bank data for the period 1980–2014 to explore the relationships between CO_2 emissions and the GDP, electricity consumption, foreign investment and financial sector development (Alaali and Naser, 2020). Its findings confirmed the validity of the EKC hypothesis. Moreover, direct foreign investments were found to reduce CO_2 emissions, whereas energy consumption increased them. Findings from another study, which also used the ARDL method to analyze World Bank time series data for the period 1980–2018 (AlZgool *et al.*, 2020), support this conclusion. However, findings on the validity of the EKC hypothesis in Bahrain, considered as part of a panel of countries, appear to be inconclusive (Table 1).

In sum, it can be concluded that the empirical literature on the relationship between CO_2 emissions and sectoral economic growth is limited in the GCC countries; only three studies were found, all of which focused only on Saudi Arabia (Alshehry and Belloumi, 2017; Mahmood *et al.*, 2018; Samargandi, 2017). Additionally, the number of empirical studies conducted in Bahrain, where data were mainly sourced from the World Bank, was relatively small. The present study contributes to the literature through an investigation of the impact of economic diversification on the environment using data collected domestically, where possible.

3. Methodology

3.1 Study area

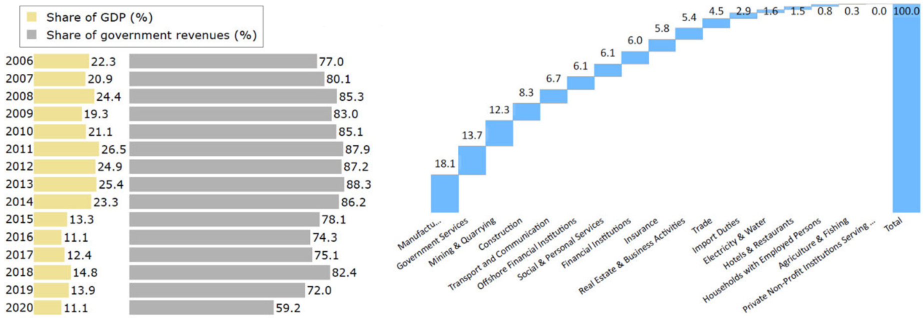
Bahrain is a small petroleum-producing country located in an arid zone, with a land area of 786.5 km^2 and a population of 1.5 million, of which 52% are expatriates (Information and eGovernment Authority, 2022). Major oil and gas discoveries in Bahrain were announced in 2018, including 80 billion barrels of shale oil and 20 trillion cubic feet of natural gas offshore (Bahrain News Agency, 2018). Although such discoveries are still at the evaluation stage to determine their financial, geological and technical feasibility, they can potentially boost Bahrain's oil and gas sector, especially given that the remaining lifetime of current oil reserves is around 5 years (Sustainable Energy Unit, 2017). Currently, most of Bahrain's crude oil supply is imported from Saudi Arabia and subsequently refined and exported, whereas natural gas is produced and fully consumed domestically (Information and eGovernment Authority, 2022). Revenues from oil and gas constituted 11% of government revenues in 2020, decreasing from 22% in 2006 (Figure 2). The oil and gas sector contributed less than 60% of Bahrain's GDP in 2020, decreasing from 77% in 2006 (Information and eGovernment Authority, 2022) (Figure 2).

Oil was discovered in Bahrain in 1932 and the first shipment was exported in 1934. Economic diversification plans were initiated in Bahrain 40 years later to reduce dependence on oil and gas as an income source. In 1975, an industrial plan was implemented, focusing on aluminum (Information and eGovernment Authority, 2022). In 2008, Bahrain's Economic Vision 2030 was launched, which included several initiatives to develop the industrial and service sectors (Information and eGovernment Authority, 2021a). The current national industry strategy for Bahrain is aimed at increasing the share of manufacturing from 12.8% up to 14.5% of the GDP by 2026. Aluminium Bahrain (Alba), which is a major aluminum-producing company, was established in 1968 and began operations in 1971. It currently produces 1.5 million metric tons and contributes to 12% of Bahrain's GDP (Alba, 2020). Aluminum production is energy intensive. Alba's electricity production and consumption

Table 1. Key studies on CO_2 emissions and economic growth in Bahrain

Study	Scope	Validity of EKC	Methodology	Data source	Main findings
Mahmood (2022)	GCC, 1990–2019	Yes		–	Financial sector development (–), Foreign direct investment (–), Exports (–)
Baydoun and Aga (2021)	GCC, 1995–2018	Yes	CS-ARDL	BP, WB	Globalization (–), energy use (+)
Zmami and Ben-Salha (2020)	GCC, 1980–2017	Yes	PMG-ARDL	WB	Energy use (+), foreign direct investment (+), urbanization (–)
Bader and Ganguli (2019)	GCC, 1980–2012	No (U- shape)	ARDL, Granger causality	WB, IMF	
Alsamara *et al.* (2018)	GCC, 1980–2017	Yes	Panel data methods, causality test	WB, UN Environment, US EIA	One-way causal relationship between GDP and emissions
Ardakani and Seyedaliakbar (2019)	MENA, 1995–2014	No (U- shape)	Multivariate linear regression	WB	
Alaali and Naser (2020)	Bahrain, 1980–2014	Yes	ARDL	WB	Electricity use (+), foreign direct investment (–)
AlZgool *et al.* (2020)	Bahrain, 1980–2018	Yes	ARDL	WB	Energy use (+), domestic credit provided to the private sector (+), trade (–)

Notes: CS = cross sectional; PMG = pooled mean group; ARDL = autoregressive distributed lag; BP = British Petroleum; UN = United Nations; WB = World Bank; MENA = Middle East and North Africa; GCC = Gulf Cooperation Council; US EIA = United States Energy Information Administration. Signs in parentheses refer to the relationship between CO_2 emissions and variables: "+" = a positive relationship, "–" = a negative relationship
Source: Created by author using results from Scopus search



Note: The oil and gas sector is a part of the mining and quarrying subsector of the GDP (right figure)

Source: Created by author using data retrieved from Information and eGovernment Authority, 2022)

Figure 2.
Oil and gas sector shares of government revenues and the GDP (left) and the GDP by sector (right; %)

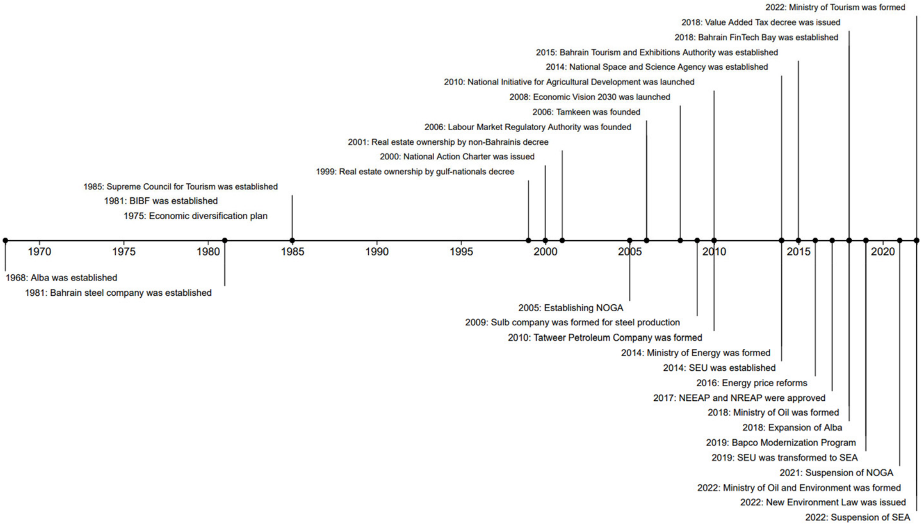
(22.2 million MWh in 2020 (Alba, 2020)) exceeds that of the national electricity grid [17.9 million MWh in 2020 (Information and eGovernment Authority, 2022)]. Alba's overall energy intensity ratio was 14.52 kWh/kg in 2020, improving from 15.2 kWh/kg in 2019. However, its energy efficiency is slightly higher than that for aluminum production in UAE, which is 13.77 kWh/kg (Emirates Global Aluminium, 2021), indicating an opportunity for improving Alba's energy efficiency.

Bahrain's target of achieving carbon neutrality by 2060 and its interim target of reducing emissions by 30% by 2035 was only announced in 2021. Previous targets mainly focused on energy. The National Energy Efficiency Action Plan (NEEAP) and the National Renewable Energy Action Plan (NREAP), with respective targets of 6% and 5% by 2025, were approved in 2017 (Figure 3). Bahrain's national action plan to achieve carbon neutrality was mentioned during the 28th United Nations Climate Change Conference of the Parties (COP 28) discussions. The action plan focuses on three dimensions: low-carbon economy, climate change adaptation and provision of sustainable opportunities within the new green economy. However, a detailed plan has not yet been published.

3.2 Methodological steps

To achieve the study's objectives, the following steps were implemented.

3.2.1 Calculating sectoral energy and carbon intensity. Energy intensity is the ratio between total energy use in a selected sector (or country) and its GDP contribution, wherein changes in economic activities are reflected in energy use and consequent CO_2 emissions. The calculation of this indicator is data intensive, and most of the required data may not be available. The energy balance prepared by the IEA for the period 1984–2019 was used to calculate the energy intensity of Bahrain's economic sectors because of data constraints. GDP data at constant prices (BHD million) were collected from the Information and eGovernment Authority of Bahrain for the same period (Information and eGovernment Authority, 2021b). The energy and carbon intensity were calculated as follows:



Notes: BIBF = Bahrain Institute of Banking and Finance; Alba = Aluminium Bahrain company; NOGA = National Oil and Gas Authority; SEU = Sustainable Energy Unit, SEA = Sustainable Energy Authority
Source: Created by author

Figure 3. Timeline of major economic and energy-related initiatives and policies in Bahrain

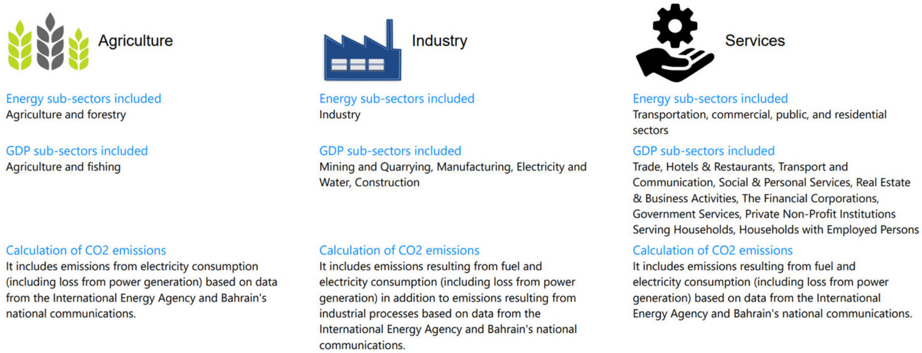
$$Sectoral\ energy\ intensity = \frac{\sum(electricity\ use + oil\ products\ use + natural\ gas\ use)}{GDP} \quad (1)$$

$$Electricity\ use = \frac{electricity\ consumption}{efficiency\ of\ electricity\ production} \quad (2)$$

$$Sectoral\ carbon\ intensity = \frac{\sum(CO2e\ from\ energy\ use + industrial\ processes + waste + agriculture)}{GDP} \quad (3)$$

Three key economic sectors were considered when calculating sectoral energy intensity, namely, the industrial, services and agricultural sectors, and all subsectors were merged accordingly (Figure 4). The CO_2 emissions attributed to energy use, industrial processes, waste and agriculture were all considered in the calculation of sectoral carbon intensity. Notably, carbon intensity is one of indicators used to measure the achievement of SDG 9, which focuses on industry, innovation and infrastructure.

3.2.2 Determining time series data trends. The Mann–Kendall and Sen's Slope tests were performed to identify the trends, magnitude and direction of CO_2 emissions, GDP and sectoral value added. The Mann–Kendall test is a nonparametric test, wherein *H0* suggests that there is no trend, and *H1* suggests a trend in the data. It was performed for time series data $x_1, x_2, \ldots, x_n$, for n years of observations for years j and k as follows (Mohammed *et al.*, 2021):



Source: Created by author, GDP sectors definitions were retrieved from World Bank (2024)

Figure 4. Sectors and subsectors included in the calculation of energy and carbon intensity

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k). \tag{4}$$

$$sgn(x_i - x_j) = \begin{cases} 1, (x_j - x_k) > 0 \\ 0, (x_j - x_k) = 0 \\ -1, (x_j - x_k) < 0. \end{cases} \tag{5}$$

The variance (VAR (S)) and Z-statistic were calculated as follows:

$$VAR(S) = \frac{1}{18}\left(n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i-1)(2t_i+5)\right). \tag{6}$$

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{VAR(S)}} S > 0 \\ 0 \qquad S = 0 \\ \dfrac{S+1}{\sqrt{VAR(S)}} S < 0, \end{cases} \tag{7}$$

where n is the number of tied groups (t_i), and m is the number of tied data. Sen's slope was calculated as follows:

$$Sen's\ slope = \left(\frac{x_j - x_i}{j - i}\right), j > i, \tag{8}$$

where x_j and x_i are data values for the time points j and i. The median of n values was calculated as follows:

$$\mathcal{E}_{med} = \begin{cases} \mathcal{E}\dfrac{(n+1)}{2} & n\,is\,odd \\ \dfrac{1}{2}\left(\mathcal{E}\dfrac{n}{2} + \mathcal{E}\dfrac{(n+2)}{2}\right) & n\,is\,even \end{cases} \tag{9}$$

3.2.3 Building econometric models Two econometric models were built to revalidate the EKC hypothesis for Bahrain (Model 1) and to determine the relationship between sectoral economic growth and CO_2 emissions (Model 2). Per capita CO_2 emissions, which is a climate change indicator, was used as a proxy for environmental quality, and per capita GDP was used as a proxy for economic growth. Time series data for 1980–2019 were used to build Models 1 and 2, as shown in Table 2. All data were converted to natural logarithms to reduce heteroskedasticity.

The ARDL approach was used to determine the relationship between CO_2 emissions and GDP as follows:

$$CO_2 = f(\text{GDP}, \text{GDPS}, \text{IND}, \text{SER}, \text{AGR}, \text{POD}), \tag{10}$$

where CO_2 represents CO_2 emissions in metric tons per capita per year, GDP is GDP in BHD (BHD = US\$2.67) at constant prices per capita per year, GDPS is the square of GDP used to examine the validity of EKC hypothesis, IND is the value added by the industrial sector to the GDP (%), SER is the value added by the services sector to the GDP (%), AGR is the value added by the agricultural sector to the GDP (%) and POD is population density, that is, the

Variable	Abbreviation	Data source
Dependent variable for Models 1 and 2		
Per capita CO_2 emissions (metric tons/capita)	CO_2	World Bank 1980–2018, IEA for 2019
Model 1		
Per capita GDP (USD/capita)	GDP	World Bank
Industry value added (% of GDP)	IND	Information and eGovernment Authority
Services value added (% of GDP)	SER	Information and eGovernment Authority
Agriculture value added (% of GDP)	AGR	Information and eGovernment Authority
Population density (people/km^2)	POD	World Bank
Model 2		
Hotels and restaurants value added (% of GDP)	HTL	Information and eGovernment Authority
Manufacturing value added (% of GDP)	MNF	Information and eGovernment Authority
Real estate and business activities value added (% of GDP)	RES	Information and eGovernment Authority
Transport and communication value added (% of GDP)	TRN	Information and eGovernment Authority

Source: Prepared by author

Table 2. Variables used in Models 1 and 2

number of people residing within an area of one square kilometer. The validity of the EKC hypothesis was tested using the following equation:

$$\mathrm{lnCO_{2t}} = {}_{\alpha 0} + \alpha_1 \mathrm{lnGDP_t} + \alpha_2 \mathrm{lnGDPS_t} + \alpha_3 \mathrm{lnIND_t} + \alpha_4 \mathrm{lnSER_t} + \alpha_5 \mathrm{lnAGR_t} + \alpha_6 \mathrm{lnPOD_t} + \mathcal{E}_\mathrm{t}, \tag{11}$$

where α_0 is the constant, $\mathscr{E}$ is the random error, and $\alpha_1 - \alpha_6$ are coefficients of variables. According to the EKC hypothesis, to obtain an inverted U-shape, α_1 should be positive and α_2 should be negative. Unit root tests were performed to evaluate stationarity in the time series data. The augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) tests were carried out, as variables are required to be integrated at the I(0) or I(1) (Menegaki, 2019).

To determine long-term relationships between variables, a cointegration test was performed using an error correction model and the Akaike Info Criterion. The value of the *F*-statistic was calculated and compared with lower and upper critical values. The null hypothesis was rejected, and cointegration was deemed to exist if the *F*-statistic value exceeded the upper critical value. The null hypothesis of no cointegration was accepted if the *F*-statistic value was below the lower critical value, while cointegration between variables was inconclusive if the *F*-statistic value was between the upper and lower critical values (Menegaki, 2019; Zafeiriou, Arabatzis, *et al.*, 2018). Once cointegration had been established, the long-term relationship was estimated using the error correction model [equation (3)], where *ECT* represented the error correction term (Ali *et al.*, 2017):

$$\Delta lnCO_{2t} = B_0 + \sum_{i=1}^{p} B_{1i}\ \Delta lnCO_{2t-i} + \sum_{i=1}^{p} B_{2i}\ \Delta lnGDP_{t-i} + \sum_{i=1}^{p} B_{3i}\ \Delta lnGDPS_{t-i} + \sum_{i=1}^{p} B_{4i}\ \Delta lnIND_{t-i} + \sum_{i=1}^{p} B_{5i}\ \Delta lnSER_{t-i} + \sum_{i=1}^{p} B_{6i}\ \Delta lnAGR_{t-i} + \sum_{i=1}^{p} B_{7i}\ \Delta lnPOD_{t-i} + \theta ECT_{t-1} + \varepsilon_t. \tag{12}$$

For Model 2, equations (13) and (14) were used to determine the relationship between sectoral economic growth and CO_2 emissions. The error correction model was estimated using equation (15) below:

$$\mathrm{CO_2} = f(\mathrm{HTL, MNF, RES, TRN}) \tag{13}$$

$$\mathrm{lnCO_{2t}} = \alpha_0 + \alpha_1 \mathrm{lnHTL_t} + \alpha_2 \mathrm{MNF_t} + \alpha_3 \mathrm{RES_t} + \alpha_4 \mathrm{TRN_t} + \mathcal{E}_\mathrm{t}. \tag{14}$$

$$\Delta lnCO_{2t} = B_0 + \sum_{i=1}^{p} B_{1i}\ \Delta lnCO_{2t-i} + \sum_{i=1}^{p} B_{2i}\ \Delta lnHTL_{t-i} + \sum_{i=1}^{p} B_{3i}\ \Delta lnMNF_{t-i} + \sum_{i=1}^{p} B_{4i}\ \Delta lnRES_{t-i} + \sum_{i=1}^{p} B_{5i}\ \Delta lnTRN_{t-i} + \theta ECT_{t-1} + \varepsilon_t, \tag{15}$$

where *HTL* denotes the value added for hotels and restaurants, *MNF* is the value added for manufacturing, *RES* is value added for real estate and business activities and *TRN* denotes value added for the transport and communications sector. To validate both models, several tests were carried out: the Breusch–Godfrey serial correlation LM test, the ARCH heteroskedasticity test, the Jarque–Bera normality test, the Ramsey RESET test, the CUSUM test and the CUSUM of squares test to assess the stability of the models.

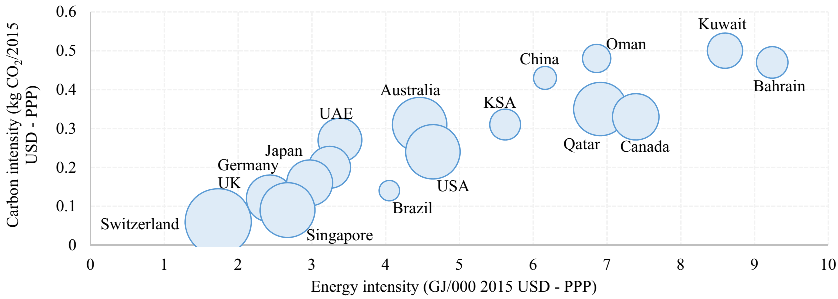
4. Results and discussion

4.1 Energy and carbon intensity of Bahrain's economic sectors

Bahrain has made efforts to diversify its economy through prioritizing specific industries, including aluminum, petrochemicals, plastics, food processing and clothing (Information and eGovernment Authority, 2022). It also focused on the services sector, specifically tourism, business services, logistics, in addition to the financial sector (Information and eGovernment Authority, 2021a).

Bahrain's economy is relatively energy intensive compared with that of many countries. However, its energy intensity is close to that of other GCC countries, resulting in a relatively carbon-intensive economy (Figure 5) (IEA, 2021b). As shown in Figure 6, sectoral energy consumption increased over time at an annual average rate of 4.6% during the period 1984–2019. The energy consumption of industrial and services sectors accounts for more than 99% of total energy use, whereas the share of the agricultural sector is minimal.

The industrial sector is highly energy intensive compared with other economic sectors in Bahrain. The energy intensity of this sector increased during the period 1984–2019, evidencing a total growth rate of 22% and reaching a value of 45 GJ/1,000 BHD (Figure 7). In 2019, the energy intensity of the services sector was the second highest at 33 GJ/1,000 BHD, while the agricultural sector was relatively energy efficient at 23.7 GJ/1,000 BHD, indicating that it consumed close to half the energy consumed by the industrial sector while producing the same GDP unit. The relatively high energy intensity of Bahrain's economic sectors is reflected in their associated carbon intensity. The carbon intensity of the industrial sector was relatively high, increasing by 75% between 1984 and 2019 and reaching 4.4 kg CO_2/BHD in 2019 (Figure 7). However, the carbon intensity of the services and agricultural sectors was lower at 1.7 kg CO_2/BHD in 2019.



Notes: Carbon intensity was measured in CO2/constant prices (US$) in 2015, and energy intensity was measured in GJ/constant prices (US$) in 2015; bubble size vcorresponds to GDP per capita (constant prices [US$] in 2015)
Source: Created by author using data retrieved from World Bank (2022); IEA (2021b)

Figure 5. Bahrain's energy and carbon intensity compared with those of several other countries

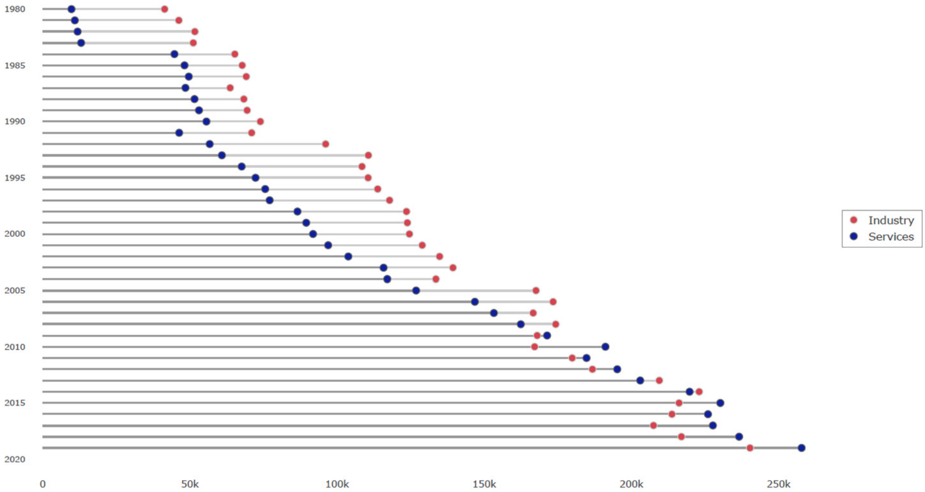


Figure 6.
Energy consumption in the industrial and services sectors (thousand tera joules)

Source: Created by author using data retrieved from World Bank (2022); IEA (2021b)

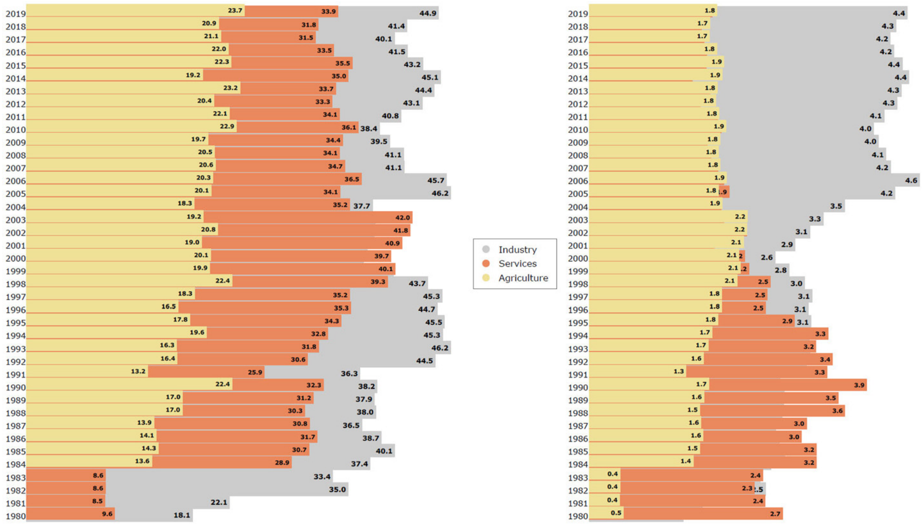


Figure 7.
Sectoral energy intensity in Bahrain during the period 1984–2019 (GJ/ constant 1,000BHD) (right bars) and sectoral carbon intensity (kg CO_2e/ BHD constant prices) (left bars)

Source: Created and calculated by author using data retrieved from Information and eGovernment Authority (2021b); IEA (2021b)

Calculating and reporting energy and carbon intensities for different economic sectors is necessary to provide inputs for environmental and economic policymaking. The available indicators provided by the IEA offer a general perspective for the economy as a whole (Figure 5). However, setting priorities and identifying opportunities for energy efficiency and emissions reduction, along with assessing the impacts on the environment of decisions relating to the economy, necessitates examining historical sectoral energy and carbon intensity trends. Accordingly, reducing energy and CO_2 emissions generated by Bahrain's industrial sector should be prioritized. Efforts to promote the industrial sector are aligned with Bahrain's economic diversification plans and with the emphasis on raising the share of industry in the GDP to achieve SDG 9. However, given that SDG 9 calls for sustainable industrialization, energy- and carbon-intensive industries, such as aluminum (Pedneault *et al.*, 2021) and cement (IEA, 2021a; Poudyal and Adhikari, 2021), require attention. Energy consumption and CO_2 emissions associated with these industries can be mitigated, as suggested in the literature. Lifecycle economic and environmental assessments are needed to determine whether the continuing existence and expansion of aluminum and cement industries in Bahrain is consistent with its recently established carbon neutrality target. The carbon intensity of Bahrain's agricultural sector (0.582 kg CO_2/US$) appears to be relatively high compared with the average value of this sector globally (0.256 kg CO_2/US$) (De Haas and Popov, 2019). However, the carbon intensities of several industries, such as the food, clothing and wood industries, are relatively low (0.186, 0.120, and 0.108 kg CO_2/USD, respectively) (De Haas and Popov, 2019), making them potentially attractive for Bahrain.

4.2 Trend analysis

The results of the Mann–Kendall and Sen's Slope tests indicated trends for nearly all the variables used in this study (Table 3). Specifically, a decrease in sectoral value added was found for services and agriculture, whereas value added by the industrial sector increased rapidly, reflecting the government's focus on the development of industries since the 1970s. Among the subsectors, value added by the manufacturing showed a rapid increase, indicated by larger values on Sen's slope, which denote a higher rate of change. This result reflects the government's promotion of this subsector.

Variable	Kendall's tau	*p*-value	Sen's slope
Main sectors			
Industry value added	0.402	0.000	0.353
Services value added	−0.354	0.001	−0.275
Agriculture value added	−0.729	<0.0001	−0.019
Subsectors			
Manufacturing value added	0.751	<0.0001	0.238
Real estate and business activities value added	−0.600	<0.0001	−0.156
Transport and communication value added	−0.115	0.296	−0.010
Hotels and restaurants value added	0.563	<0.0001	0.026
Sectoral energy intensity			
Energy intensity for industry	0.346	0.002	0.184
Energy intensity for services	0.367	0.001	0.191
Energy intensity for agriculture	0.669	<0.0001	0.276
Other variables			
Per capita CO_2 emissions	−0.354	0.001	−0.092
Per capita GDP	0.963	<0.0001	273.456
Population density	0.980	<0.0001	37.914
CO_2 emissions	0.952	<0.0001	0.633
Population	0.983	<0.0001	30,638.216

Source: Results of analysis conducted by author, source of raw data Information and eGovernment Authority (2021b, 2022); World Bank (2022); IEA (2021b)

Table 3. The results of the Mann–Kendall and Sen's slope tests

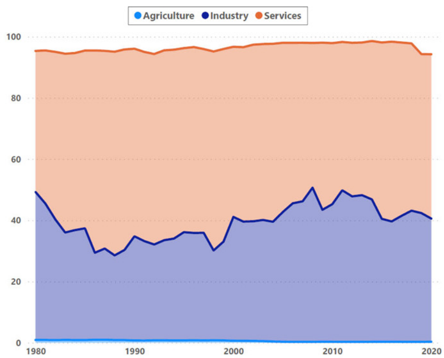
Promotion of tourism also appears to be rewarding, as the value added by hotels and restaurants to the GDP is increasing. However, given that the focus on tourism is recent, this trend was less apparent.

Trends for sectoral energy intensity showed a rapid rise in energy consumption for generating GDP (Table 3). The rate of change for agricultural energy intensity was the highest among Bahrain's economic sectors, indicating that this sector consumes more energy to produce one unit of the GDP compared with the industrial and services sectors. This finding also highlights opportunities for improving energy efficiency in the agricultural sector by deploying renewable energy technologies and selecting higher-value products (Nugroho *et al.*, 2022). Given Bahrain's prioritization of food security, the above recommendations are especially urgent.

4.3 Revalidating the Environmental Kuznets Curve hypothesis

An econometric model was built to revisit the validity of EKC hypothesis in the specific context of Bahrain. Figure 8 depicts descriptive statistics for variables used in the model. The results of unit root tests (ADF and PP) revealed that all variables were stationary at level or first difference, which meets the requirement for ARDL. The results also demonstrated that the value of the *F*-statistic exceeded the upper limit at a significance level of 1%, implying that a relationship of cointegration existed between variables. Therefore, a relationship existed between the dependent variable, that is CO_2 emissions, and independent variables, and long- and short-term coefficients were estimated.

The results for Model 1 revealed that none of the coefficients of the GDP, GDPS, agricultural or services sectors were significant in the long term (Table 4). For the industrial sector, a positive relationship between growth in the industrial sector's share of GDP and per capita CO_2 emissions was evident at a significance level of 10%. However, the relationship between population density and emissions was negative at a 1% significance



Column1	CO2	GDP	IND	SER	AGR	POD	HTL	MNF	RES	TRN
Count	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Kurtosis	1.87	3.66	1.98	2.21	1.34	1.82	2.69	2.16	1.79	2.97
Maximum	26.15	9,252.06	50.41	66.58	0.96	1,926.97	2.70	18.51	10.84	7.77
Mean	23.05	8,074.44	38.83	57.16	0.59	1,074.85	2.04	12.56	7.95	6.75
Median	22.98	8,121.10	39.22	57.69	0.67	886.32	2.08	11.90	8.19	6.89
Minimum	19.85	7,381.39	27.67	46.08	0.26	506.90	1.24	7.91	4.99	5.22
Skewness	-0.09	0.44	0.02	-0.15	-0.10	0.53	-0.60	0.29	-0.19	-0.75
Standard Deviation	1.73	416.64	6.36	5.40	0.26	468.28	0.38	2.99	1.82	0.65

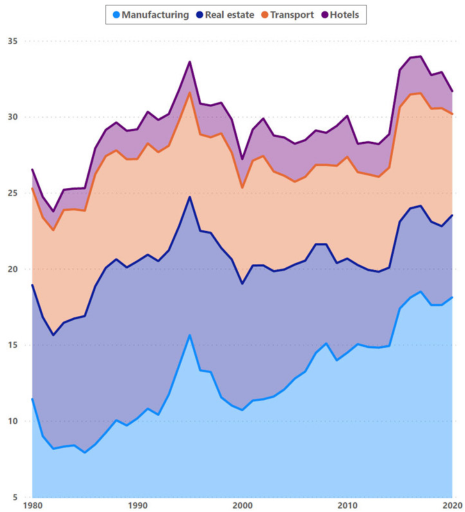


Figure 8.
Descriptive statistics for variables used in Models 1 and 2

Source: Results of analysis conducted by author, source of raw data Information and eGovernment Authority (2021b, 2022); World Bank (2022); IEA (2021b)

Long term		Short term	
Variable	Coefficient	Variable	Coefficient
Model 1			
LNGDP	−2.709	D(LNGDP)	0.786
LNGDPS	0.150	D(GDPS)	−0.036
LNIND	2.686*	D(LNIND)	−0.294
LNSER	2.579	D(LNSER)	−0.527*
LNAGR	0.085	D(LNAGR)	0.023
LNPOD	−0.559***	D(LNPOD)	−0.288**
C	−1.070	CointEq(−1)	−0.514***
Model 2			
LNHOT	−0.274***	D(LNHOT)	−0.007
LNMAN	0.280***	D(LNMAN)	0.060
LNREAL	0.325***	LNREAL	−0.262***
LNTRAN	−0.297***	D(LNTRAN)	0.287***
C	2.522***	CointEq(−1)	−0.882***

Notes: *Statistical significance at the 10% level; **statistical significance at the 5% level; ***statistical significance at the 1% level
Source: Results of analysis conducted by author, source of raw data Information and eGovernment Authority (2021b, 2022); World Bank (2022); IEA (2021b)

Table 4. Coefficients of variables in the long and short term in Model 1 and Model 2

level, with an increase in population density by 55% associated with a 1% decrease in per capita CO_2 emissions. All coefficients were statistically insignificant in the short term with the exception of value added by the services sector and population density, which were negatively related to CO_2 emissions at significance levels of 10% and 5%, respectively (Table 4).

These results suggest that the EKC hypothesis is invalid for Bahrain, as the relationship between economic growth and CO_2 emissions assumed a U-shape in the long-term estimation and an inverted U-shape in the short-term estimation, with neither being statistically significant at the 10% level. This conclusion supports those of several studies (Ardakani and Seyedaliakbar, 2019; Bader and Ganguli, 2019), which reported a U-shaped relationship for Bahrain when it was studied among a panel. However, this finding contradicts those of other studies (Alaali and Naser, 2020; AlZgool *et al.*, 2020), which found that the EKC hypothesis was valid for Bahrain. Variations in findings related to the validity of the EKC hypothesis are evident in the literature, for example, for Saudi Arabia (AlKhars *et al.*, 2022). The reason for these different findings may be attributed to the use of different time series data and the inclusion of different variables (AlKhars *et al.*, 2022). In particular, most of the variables included in Model 1 in the present study were not included in earlier studies (Alaali and Naser, 2020; AlZgool *et al.*, 2020).

The results of the present study confirm those of (Samargandi, 2017), who found that the growth of industry was linked to that of CO_2 emissions in Saudi Arabia, at 10% and 5% levels of significance in the long and short terms, respectively. Whereas Samargandi found a positive relationship between the growth of the services sector and emissions in Saudi Arabia in the short term, the results of the present study suggest that this relationship is negative in the short term in Bahrain. Moreover, the findings of this study suggest that the relationship between population density and CO_2 emissions is negative for Bahrain, which is consistent with those in the international literature (Hassan and Nosheen, 2019).

4.4 Sectoral economic growth and CO_2 emissions

Figure 8 depicts descriptive statistics for variables used in Model 2. The results of the ADF and PP unit root tests indicated that all variables were stationary at level or first difference. The value of the *F*-statistic was higher than the upper critical values at a significance level of 1%, suggesting that the variables are cointegrated, which enables an exploration of the relationship between CO_2 emissions and sectoral economic growth in the short and long terms. The results obtained for Model 2 suggest that the coefficients of all variables were statistically significant at the 1% level, indicating that the growth of economic subsectors is linked to an increase in CO_2 emissions in the long run. A negative relationship was found between a rise in emissions and economic growth in the hotel and transportation sectors, whose respective growth by 27% and 29% contributed to a 1% reduction in CO_2 emissions in the long run (Table 4). Conversely, growth in the real estate sector and manufacturing industries by 28% and 32%, respectively, contributed to a 1% increase in CO_2 emissions in the long run in Bahrain.

Growth in the real estate sector appears to be negatively associated with CO_2 emissions in the short term, whereas a positive relationship was found between growth in the transportation sector and emissions at a significance level of 1%. Hotels, especially chain-branded ones, have demonstrated a commitment to reducing their ecological and carbon footprints. The electricity and water authority in Bahrain provides technical support to the commercial sector, specifically hotels, for conducting energy audits and installing solar panels. Therefore, there is a negative correlation between growth in the hospitability sector and CO_2 emissions in Bahrain. Among the manufacturing industries, the types and extent of industrial activities determine energy demands and associated emissions. The presence of relatively carbon-intensive industries in Bahrain resulted in a positive relationship between the growth of manufacturing industries and CO_2 emissions in the short run. A similar finding was reported for Indonesia, where the growth of these industries is related to an increase in CO_2 emissions (Prastiyo *et al.*, 2020).

The relationship between the growth of the real estate sector and CO_2 emissions was found to be positive in the long term. This is because the expansion of buildings, and specifically housing units, implies rising energy demands and consequently increasing CO_2 emissions, given that renewables still account for a minimal share of Bahrain's energy mix.

The results for Model 2 are consistent with calculations of sectoral energy and carbon intensity (Section 4.1). Economic diversification and expansion of the services sector (hotels, transportation, and communications in particular) appear to be in alignment with the carbon neutrality target. However, an emphasis on reuse and recycling activities may be beneficial through emissions reduction. Therefore, more stringent energy efficiency and renewable energy-related requirements for new buildings are recommended. The results of the diagnostic tests performed for Models 1 and 2 are depicted in Table 5 and Figures 9 and 10, indicating the stability of the estimations.

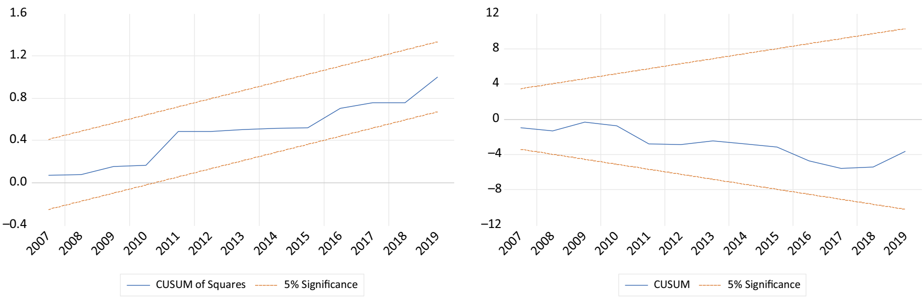
5. Conclusions

This study was aimed at exploring the relationship between sectoral economic growth and CO_2 emissions in Bahrain. The findings revealed relatively high energy and carbon intensities for the industrial sector, compared with other countries (World Bank, 2022; IEA, 2021b). The EKC hypothesis proved invalid for Bahrain, in contrast to (Alaali and Naser, 2020; AlZgool *et al.*, 2020). The relationship between sectoral economic growth and CO_2 emissions varied; it was negative for hotels and transportation but positive for manufacturing industries and real estate, which was consist with findings from other countries (Samargandi, 2017; Prastiyo *et al.*, 2020). Accordingly, a focus on expanding the services sector along with the adoption of circular economy concepts, and a shift from energy-intensive industries to less energy-intensive ones, notably recycling, can help to harmonize efforts to achieve economic diversification and carbon neutrality (Alsabbagh and Alnaser, 2022).

Table 5. The results of diagnostic tests performed for Models 1 and 2

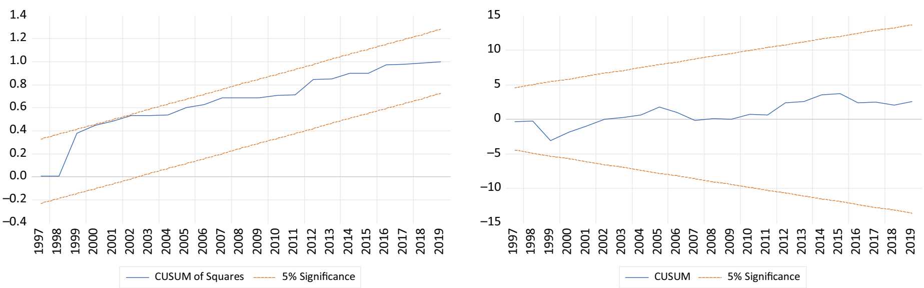
Test	Coefficient (significance) Model 1	Model 2
R-squared	0.947	0.866
Adjusted *R*-squared	0.858	0.797
F-statistic	10.615	12.461 (0.000)
Breusch–Godfrey Serial Correlation LM Test	0.963 (0.411)	0.562 (0.578)
Heteroskedasticity Test: ARCH	0.124 (0.726)	0.444 (0.509)
Jarque–Bera Normality Test	1.734 (0.420)	0.059 (0.970)
Ramsey RESET Test	0.161 (0.695)	0.018 (0.891)

Source: Results of analysis conducted by author, source of raw data: Information and eGovernment Authority (2021b, 2022); World Bank (2022); IEA (2021b)



Source: Results of analysis conducted by author, source of raw data Information and eGovernment Authority (2021b, 2022); World Bank (2022); IEA (2021b)

Figure 9. The results of the stability tests performed for Model 1



Source: Results of analysis conducted by author, source of raw data Information and eGovernment Authority (2021b, 2022); World Bank (2022); IEA (2021b)

Figure 10. The results of the stability tests performed for Model 2

This study of Bahrain offers several lessons. First, interlinkages between economic and environmental policies need to be identified and addressed to ensure policy coherence. The formulation of sector-specific policies and targets can better address economic and environmental issues compared with setting broad targets. Second, economy-wide changes are required to achieve carbon neutrality. Sometimes small modifications in activities or processes may be sufficient. However, industrial restructuring may prove effective. In this context, alternatives to energy-intensive industries in Bahrain, notably the aluminum and steel industries, merit further study using a lens of economic and environmental lifecycles and social welfare to ensure meeting the SDGs.

A primary recommendation emerging from this study is the need to explore the relationship between economic growth and a set of indicators of environmental quality, such air pollution and waste generation. Adopting a holistic approach for assessing the impacts of economic activities on a wide range of environmental indicators can better inform policymaking and the setting of feasible economic and environment targets for each sector, developing plans and attracting investments. Collaborations among GCC countries involving GCC-STAT (the regional statistical center) could prove beneficial, especially in terms of data collection, and calculations of relevant indicators. The use of such indicators is also essential for examining potential pathways for achieving sustainable development.

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