Energy consumption, carbon emissions and economic growth in Saudi Arabia: An aggregate and disaggregate analysis

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HIGHLIGHTS
- Carbon emissions increase with the increase in per capita income in Saudi Arabia.
- The income elasticity of CO2 is negative for the gas consumption model.
- The income elasticity of CO2 is positive for the oil consumption model.
- The results suggest that electricity is less polluting than oil and gas.

ABSTRACT
The objective of this study is to examine the relationship among economic growth, carbon emissions and energy consumption at the aggregate and disaggregate levels. For the aggregate energy consumption model, we use total energy consumption per capita and CO2 emissions per capita based on the total energy consumption. For the disaggregate analysis, we used oil, gas and electricity consumption models along with their respective CO2 emissions. The long-term income elasticities of carbon emissions in three of the four models are positive and higher than their estimated short-term income elasticities. These results suggest that carbon emissions increase with the increase in per capita income which supports the belief that there is a monotonically increasing relationship between per capita carbon emissions and per capita income for the aggregate model and for the oil and electricity consumption models. The long- and short-term income elasticities of carbon emissions are negative for the gas consumption model. This result indicates that if the Saudi Arabian economy switched from oil to gas consumption, then an increase in per capita income would reduce carbon emissions. The results also suggest that electricity is less polluting than other sources of energy.

ARTICLE INFO
Article history:
Received 29 April 2013
Accepted 16 July 2013
Available online 19 August 2013

Keywords:
Oil
Gas
CO2

1. Introduction
In recent years, environmental pollution, greenhouse gases and climate change have become among the most important environmental concerns worldwide. The ever-increasing levels of carbon dioxide (CO2) and other greenhouse gases in the atmosphere are considered to be among the world’s greatest environmental threats. Among the greenhouse gases, CO2 plays a powerful role in enhancing the greenhouse effect and is responsible for greater than 60 percent of this effect (Ozturk and Acaravci, 2010). Energy production and consumption patterns, energy intensity, the price and availability of energy play an important role in CO2 emissions development trends. Energy is considered an engine of industrial development and economic growth; thus, it is believed that a country with high energy consumption also has a high living standard. However, high energy consumption also causes high carbon emissions, which adversely affect the environment. Thus, the effects of global warming and climate change on the world economy have been studied intensively by academics and practitioners. The empirical literature shows that the relationship between per capita income and environmental pollution follows an inverted U-shaped pattern, which is commonly known as the environmental Kuznets curve (EKC). According to the EKC hypothesis, at early stages of economic growth, degradation and pollution increases, but beyond some level of income per capita, the trend reverses, such that a high level of income leads to environmental improvement (Stern, 2004). There is a wide range of literature that has assessed the relationships among energy consumption, economic growth and carbon emissions. The empirical evidence suggests that there is a long-term relationship between pollution levels and economic growth; therefore, any constraint that is
placed on energy consumption to aid in reducing emissions will have a negative effect on economic growth (Ozturk and Acaravci, 2010; Halicioglu, 2009; Chontanawat et al. 2008; Lise, 2006; Lee, 2005; Soytas and Sari, 2003).

The United Nations has been seriously attempting to reduce the adverse effects of global warming and climate change through binding agreements, such as the Kyoto Protocol (Halicioglu, 2009). The Protocol was initially adopted on December 11, 1997, in Kyoto, Japan, and entered into force on February 16, 2005. As of September 2001, 191 countries had signed and ratified the protocol. The Kyoto Protocol is generally considered an important development toward a truly global emissions reduction regime that will stabilize greenhouse gas emissions and provide the essential architecture for any future international agreements on climate change. Therefore, promoting sustainable development and combating climate change have become integral aspects of energy planning, analysis and policy making in many countries of the world, including Saudi Arabia.

The Saudi Arabian government has taken many important and constructive steps to preserve its natural resources. To achieve the lowest possible level of energy intensity, Saudi Arabia has actively participated in the global trend to preserve the environment through a combination of positive initiatives and environmental regulation. Saudi Arabia has revised its general environmental laws and the rules for their implementation to be consistent with Article 32 of the constitution with the following aims:

- “The State shall endeavor to preserve, protect and improve the environment and prevent its pollution.
- Protect public health from activities and acts that harm the environment.
- Conserve and develop natural resources.
- Include environmental planning as an integral part of overall development planning in all industrial, agricultural, architectural and other areas.
- Raise awareness of environmental issues and strengthen individual and collective feelings regarding the sole and collective responsibility for preserving and improving the environment and encouraging national voluntary efforts.
- Address various types of environmental violations and appropriate penalties for protecting the human health from pollution both at present and in the future”.

The Saudi Arabian economy is an oil-based economy and comprises energy-intensive sectors such as the industry, building and transport sectors. Therefore, total energy consumption is increasing rapidly in the country despite the measures and regulations that have been adopted. According to Saudi Arabia’s Energy Efficiency Report (January 2011), energy consumption is growing more rapidly than GDP in Saudi Arabia, and primary energy consumption per capita was 6.8 toe in 2009, which is four times higher than the world average. Total energy consumption is growing at an average rate of 5.8 percent per year since 1990, and the rate has tripled between 1990 and 2009. The final and primary energy intensities rose by 2.3 percent per year, on average, between 2000 and 2009, and CO2 intensity has risen by 2 percent per year since 2000 (Saudi Arabia’s Energy Efficiency Report, 2011).

The choice of Saudi Arabia for this study is motivated by the fact that Saudi Arabia has experienced a sharp increase in energy consumption and carbon emissions in recent years as a result of its strong economic and industrial growth. Historically high international oil prices and large domestic fuel subsidies also play an important role in the recent economic growth and high energy consumption in the country. Because of strong economic and industrial growth, the consumption of oil, gas and electricity increased sharply during the 1980–2010 period. In 2010, Saudi Arabia’s oil consumption was approximately 2.65 million barrels/day, which is 4.3 times the 1980 level. Electricity consumption reached 478 billion kWh, and gas consumption reached 3095.7 billion cubic feet in 2010, which are 9.7 and 9.3 times their 1980 levels, respectively (U.S. Energy Information Administration, 2012). According to Boden et al. (2011), Saudi Arabia’s share of carbon emissions worldwide in 2008 was at 14th place, or a 1.54 percent share of worldwide emissions, with 118 million metric tons of carbon emissions.

The steps that have been taken by the Saudi Arabian government to protect the environment by preserving energy resources have important implications for the sustainable development of the country. The literature suggests that any effective policy should consider the dynamic nature of the relationships among energy, the environment and growth and should have a long-term vision. Hence, understanding the intertemporal relationship among emissions, energy use and economic growth in an individual country is essential to generate effective policies (Soytas and Sari, 2009). There is no country-level study for Saudi Arabia that focuses on aggregate and disaggregate analyses of energy consumption, carbon emission and growth. Therefore, one objective of this study is to investigate the existence of the EKC for Saudi Arabia for aggregate and disaggregate energy consumption and carbon emission data. For the aggregate analysis, we use total energy consumption per capita and per capita CO2 emissions from the total energy consumption. We disaggregate the total energy consumption into oil, gas and electricity consumption to examine the separate effect of each of these types of energy consumption on CO2 emissions. Therefore, for the disaggregate analysis, we use oil, gas and electricity consumption along with their respective CO2 emissions. The other objective of the study is to examine the long- and short-term causal relationships among economic growth, carbon emissions and energy consumption at the aggregate and disaggregate levels of energy consumption and carbon emissions to determine whether Saudi Arabia can achieve its objective of an environmental friendly atmosphere without compromising its sustainable economic growth pattern. This paper also addresses the collinearity and omitted variable bias problems in the estimation methodology. As Stern (2004) and Narayan and Narayan (2010) noted, most of the EKC literature is econometrically weak. Earlier studies model carbon emissions as a function of income augmented by income-squared and income-cubed type variables, which suffer from multicollinearity problems. A test of collinearity between income and income squared for Saudi Arabia has been conducted, and the correlation between income and income squared is determined to be 0.9999 for the 1980–2011 period. The previous studies (for example, Narayan and Narayan, 2010; Alam et al., 2012) relied on a bivariate analysis and thus suffered from an omitted variable bias problem.

The remainder of this study is organized as follows. Section 2 discusses the empirical literature on the relationship among economic growth, carbon emissions and energy consumption. Section 3 discusses the data and methodology used in the study. Section 4 presents the empirical findings, and the conclusion and policy implications are included in Section 5.

2. Literature review

The literature on the relationship among economic growth, energy consumption and environmental pollution has three broad strands (Zhang and Cheng, 2009). The first strand of the literature focuses on environmental pollution and the economic growth nexus. This strand of the literature involves testing for the existence of an EKC, which states that in the early stages of economic growth,
environmental quality decreases with the increase in per capita income, but after a certain level, quality begins to improve again with an increase in the per capita income level. This relationship implies that the environmental impact indicator is an inverted U-shaped function of per capita income. In the EKC hypothesis, the logarithm of the indicator is modeled as a quadratic function of the logarithm income. The EKC hypothesis was initially proposed and tested by Grossman and Krueger (1991). Subsequently, the studies of Stern (2004) and Dinda (2004), among others, have provided extensive review surveys of the studies that tested the economic growth and environmental pollution nexus. Therefore, the standard EKC regression model is as follows:

$$\ln(E/P) = \alpha + \beta_1 \ln(GDP/P) + \beta_2 [\ln(GDP/P)]^2 + \epsilon_t$$

where $E$ is emissions, $P$ is population, GDP is the gross domestic product and $\ln$ indicates the natural logarithm. The turning point or threshold level for maximum emissions is given by $t = \exp(-\beta_1/2\beta_2)$.

The second strand of the literature is related to energy consumption and the output nexus. This strand of the literature suggests that economic growth and energy consumption are closely related, as a higher level of economic development requires greater energy consumption. An extensive number of studies have assessed the empirical evidence using the Granger causality test and the cointegration model. These earlier studies have primarily applied bivariate models and have failed to obtain consensus results. The literature regarding the empirical results from the causality test between energy consumption and economic growth presents four different results. The first result is the unidirectional causality from energy consumption to economic growth, which is also known as the growth hypothesis. Empirical studies that have provided evidences in support of the growth hypothesis include the works of Stern (2000), Soytas and Sari (2003), Oh and Lee (2004), Altinay and Karagol (2005), Sari et al. (2008), and Narayan and Smyth (2008). The second result is the unidirectional causality from economic growth to energy consumption, which is also known as the conservation hypothesis. Among other works, the studies by Ghosh (2002), Soytas and Sari (2003), Narayan and Smyth (2005), Mehrara (2007), Halicioglu (2007), Asghar (2008), Lise and Van Montfort (2007), Sari et al. (2008), and Dhungel (2008) support the conservation hypothesis. The third result is the bidirectional causality between economic growth and energy consumption, which is also known as the feedback hypothesis. Evidence for the feedback hypothesis has been provided by Masih and Masih (1997), Asafu-Adjaye (2000), Chali and El-Sakka (2004), Paul and Bhattacharya (2004), Lee (2006), Lee and Chang (2007), Kahlai et al. (2010), and Shahbaz and Lean (2012a). The final result is that no causal relationship exists between economic growth and energy consumption; this hypothesis is known as the neutrality hypothesis. The findings of the neutrality hypothesis are supported by Cheng (1996), Fatai et al. (2002), Altinay and Karagol (2005), Akbostanci et al. (2009), Halicioglu (2009), Zhang and Cheng (2009), Kijima et al. (2010), Nasir and Rehman (2011), Shahbaz and Lean (2012b), Hamit-Haggar (2012), Ozturk and Acraci (2012), Esteve and Tamarit (2012), Shahbaz et al. (2012, 2013a, 2013b), Tiwari et al. (2013), among others. However, these studies modeled carbon emissions as a function of income, income squared and/or income cubed in addition to other explanatory variables; thus, they suffered from problems of collinearity or multicollinearity (Narayan and Narayan, 2010). Narayan and Narayan also observed that attempts to define the turning point in the EKC hypothesis suffer from model misspecification problems. These authors proposed that environmental quality can be evaluated by comparing the short-term and long-term income elasticities. The authors argue that if the long-term income elasticity is less than the short-term income elasticity, then it can be inferred that increased income leads to decreased CO₂ emissions over time. Narayan and Narayan (2010) examined the EKC hypothesis for 43 developing countries based on short- and long-term income elasticities. Shahbaz et al. (2013c) examined the multivariate dynamic relationship between economic growth, energy consumption, financial development, trade openness and CO₂ emission for Indonesian economy. This study did not include the income square term in estimation equation. Their results indicate that economic growth and energy consumption have a significant positive effect on CO₂ emissions, while financial development and trade openness have significant negative impact on CO₂ emissions. Alam et al. (2012) examined both short- and long-term causality and joint causality within an error correction framework for Bangladesh. The works of Narayan and Narayan (2010) and Alam et al. (2012) relied on a bivariate analysis and thus suffered from an omitted variable bias problem. The current study is attempting to avoid both the omitted variable bias and collinearity problems by examining the relationship among carbon emissions, energy consumption and economic growth in Saudi Arabia.

### 3. Model specification and data

To avoid the omitted variable bias and collinearity problems, this study will be based on a standard log-linear functional relationship among carbon emissions per capita, total energy consumption per capita and real GDP per capita. We employ the following linear logarithmic model:

$$co_t = a_0 + a_1 ec_t + a_2 y_t + et$$

(1)

where $co_t$ is CO₂ emissions per capita, $ec_t$ is total energy consumption per capita, $y_t$ is real GDP per capita and $et$ is the error term. To examine the separate effect of these types of energy consumption on economic growth and CO₂ emissions and on the basis of Eq. (1), this study disaggregates total energy consumption into oil, gas and electricity consumption along with their respective CO₂ emissions as follows.

(1) The model for oil consumption in Saudi Arabia is as follows:

$$co_{o_t} = y_{0t} + y_{1} oc_{t} + y_{2} y_{t} + e_{2t}$$

(2)

where $co_{o_t}$ is CO₂ emissions per capita from the consumption of oil, $oc_{t}$ is per capita oil consumption and $e_{2t}$ is the error term.

(2) The model for gas consumption in Saudi Arabia is as follows:

$$co_{g_t} = \delta_0 + \delta_1 gc_{t} + \delta_2 y_{t} + e_{3t}$$

(3)

where $co_{g_t}$ is CO₂ emissions per capita from the consumption of gas, $gc_{t}$ is the per capita gas consumption and $e_{3t}$ is the error term.

(3) The model for electricity consumption in Saudi Arabia is as follows:

$$co_{el_t} = \delta_0 + \delta_1 el_{ct} + \delta_2 y_{t} + e_{4t}$$

(4)

where $co_{el_t}$ is the CO₂ emissions per capita from the production of electricity and heat, $el_{ct}$ is the per capita electricity consumption
and $\varepsilon_t$ is the error term. Because the data for CO$_2$ emissions from electricity consumption are not available for Saudi Arabia, we use CO$_2$ per capita from the production of electricity and heat as a proxy for CO$_2$ emissions from electricity consumption. The lower case letters in Eqs. (1)–(4) demonstrate that all variables are in natural logarithms.

The annual time series data from 1980 to 2011 on CO$_2$ emissions from the consumption of natural gas (million metric tons), CO$_2$ emissions from the consumption of oil (million metric tons), natural gas consumption (billion cubic feet), per capita CO$_2$ emissions from the consumption of energy (metric tons of CO$_2$ per person), total oil consumption (thousand barrels per day) and total energy consumption per capita (million Btu per person) are obtained from the U.S. Energy Information Administration, 2012. Per capita GDP, CO$_2$ emissions from electricity and heat production, (million metric tons) and electric power consumption (kilowatt hours per capita) data are obtained from the World Development Indicators (2012) online database. All of the variables are converted into per capita form.

3.1. Econometrics methodology

The autoregressive distributed lag (ARDL) approach to cointegration proposed by Pesaran et al. (2001) has been used in this study. This approach has several advantages. (1) This approach can be applied irrespective of whether the explanatory variables are I(0) or I(1). (2) The ARDL approach captures both short- and long-term dynamics when testing for the existence of cointegration. (3) The approach offers explicit tests for the existence of a unique cointegration vector rather than assuming that it exists. (4) Finally, this approach is preferable for small samples.

An ARDL representation of Eqs. (1)–(4) is formulated as follows:

$$\Delta c_d = \alpha_0 + \sum_{i=1}^{p} \beta_1 \Delta c_{d,t-i} + \sum_{i=0}^{p} \beta_2 \Delta e_{c,t-i} + \sum_{i=0}^{p} \beta_3 \Delta y_{t-i} + \beta_D D + \varepsilon_t$$

(5)

where $c_d$ is the carbon emissions per capita from aggregate energy, oil, gas, and electricity consumption, and $e_{c}$ represents the aggregate energy, oil, gas, electricity consumption and $D$ is the dummy for structural break in the data. Following Shahbaz et al. (2013b), we use dummy variable in ARDL specification to capture the effect of structural break in the data.

Eq. (5) is estimated using ordinary least squares (OLS) to explore the long-term relationship among the variables by conducting an F-test for the joint significance of the lagged-level variables. The null hypothesis of no cointegration in Eq. (5) is $H_0$: $\beta_1=\beta_2=\beta_3=0$ against the alternative that $H_1$: $\beta_1 \neq 0$, $\beta_2 \neq 0$, $\beta_3 \neq 0$.

If the F-statistic lies below the lower bound, then this result implies that there is no cointegration. If the F-statistic is above the upper bound, then the result implies that there is cointegration. If the F-statistic falls between the upper bound and lower bound, then the test would be inconclusive. If the variables are found to be cointegrated in the first step, then in the second step, the long- and short-term models can be estimated as represented by Eqs. (6) and (7) below, respectively:

$$c_d = \alpha_2 + \sum_{i=1}^{p} \beta_1 c_{d,t-i} + \sum_{i=0}^{p} \beta_2 e_{c,t-i} + \sum_{i=0}^{p} \beta_3 y_{t-i} + \varepsilon_t$$

(6)

$$\Delta c_d = \alpha_3 + \sum_{i=1}^{p} \beta_1 \Delta c_{d,t-i} + \sum_{i=0}^{p} \beta_2 \Delta e_{c,t-i} + \sum_{i=0}^{p} \beta_3 \Delta y_{t-i}$$

(7)

where $\varphi$ represents the coefficient of the error correction term ($ECT$), which is defined as follows:

$$ECT_{t-1} = c_{d,t} - \alpha_2 - \sum_{i=0}^{p} \beta_2 e_{c,t-i} - \sum_{i=0}^{p} \beta_3 y_{t-i}$$

3.2. Causality analysis

The ARDL cointegration approach confirms the existence or absence of a long-term relationship between the variables included in the model. However, the existence of cointegration does not indicate the direction of causality. We use a vector error correction model (VECM) approach to detect the direction of causality. Toda and Philips (1993) indicated that if a long-term relationship exists, then an error correction model can be used to determine the direction of causality. The VECM for the three variables can be written as follows:

$$\Delta c_d = \alpha_3 + \sum_{i=1}^{p} \beta_1 \Delta c_{d,t-i} + \sum_{i=0}^{p} \gamma_1 \Delta e_{c,t-i} + \sum_{i=0}^{p} \delta_1 \Delta y_{t-i}$$

$$+ \varphi_1 ECT_{t-1} + \varepsilon_t$$

(8)

$$\Delta y_t = \alpha_3 + \sum_{i=1}^{p} \beta_2 \Delta c_{d,t-i} + \sum_{i=0}^{p} \gamma_2 \Delta e_{c,t-i} + \sum_{i=0}^{p} \delta_2 \Delta y_{t-i}$$

$$+ \varphi_2 ECT_{t-1} + \varepsilon_t$$

(9)

$$\Delta e_{c,t} = \alpha_3 + \sum_{i=1}^{p} \beta_3 \Delta c_{d,t-i} + \sum_{i=0}^{p} \gamma_3 \Delta e_{c,t-i} + \sum_{i=0}^{p} \delta_3 \Delta y_{t-i}$$

$$+ \varphi_3 ECT_{t-1} + \varepsilon_t$$

(10)

where $ECT_{t-1}$ is the lagged error correction term derived from the long-term cointegration relationship, and $\varphi_i$ are the speed of adjustment, showing how much disequilibrium is corrected within one period. An error correction model also enables us to distinguish between long-term and short-term Granger causality. The direction of short-term Granger causality can be tested statistically using the joint significance of the coefficients of each explanatory variable. The direction of long-term Granger causality can be determined by testing the significance of the coefficient of the error correction term in each equation using the t-test. Finally, we test whether the two sources of causation (short and long term) are jointly significant. This joint test of causality demonstrates which variable bears the burden of a short-term adjustment to re-establish a long-term equilibrium (Asafu-Adjaye, 2000; Oh and Lee, 2004).

4. Empirical results

The time series properties of the data are tested using augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) statistics. Table 1 displays the results of the ADF and PP tests on the integration of the variables. The results indicate that each variable is integrated of order one except for GDP per capita ($y$); thus, all of the variables are non-stationary at their level and stationary at first difference, i.e., I(1), and $y$ is stationary at level, i.e., I(0). Both unit root tests, ADF and PP, reveal that all dependent variables are integrated of order one and that the independent variables are I(0) or I(1). Therefore, in this situation, ARDL is an appropriate estimation methodology.

However, Perron (1989) argues that in the presence of a structural break, the standard ADF tests are biased towards the non-rejection of null hypothesis. Similarly, Shahbaz et al. (2013b) pointed out that ADF unit root test by Dickey and Fuller and p–p test by Phillips and Perron do not take into account the structural break in data. Therefore, these tests provide biased and spurious results. Zivot and Andrews (1992) proposed three models to determine the break points endogenously to test the time series properties of data. Zivot and Andrews methodology is based on the assumption of unknown breakpoint in the deterministic trend
function. In their methodology, model (A) allows one-time exogenous change in a variable at a level form, model (B) allows for one time shift in the slope of the trend component and model (C) allows for one time change in both intercept and trend function of the variables (Shahbaz et al. 2013b). Zivot and Andrews (1992) test for a unit root in Models (A)
\[ \Delta y_t = \alpha_0 + \alpha_1 D\Delta y_{t-1} + \rho y_{t-1} + \sum_{i=1}^{p} \phi_i \Delta y_{t-i} + \epsilon_t \]
Model (B) \[ y_t = \alpha_0 + \gamma D\Delta t + \beta y_{t-1} + \sum_{i=1}^{p} \phi_i \Delta y_{t-i} + \epsilon_t \]
Model (C) \[ y_t = \alpha_0 + \alpha_1 D\Delta y_{t-1} + \gamma D\Delta t + \beta y_{t-1} + \sum_{i=1}^{p} \phi_i \Delta y_{t-i} + \epsilon_t \]
where \( D\Delta \) is the intercept dummy indicates a one-time shift in the level; \( D\Delta y_{t-1} \) and zero otherwise; \( D\Delta t \) is the slope dummy represent a change in the slope of the trend function; \( D\Delta t = -1 \) if \( t > TB \) and zero otherwise; and \( TB \) is the break date.\(^1\)

Table 2 displays the results of the Zivot–Andrews structural break trended unit root test. The results demonstrate that each variable is non-stationary at their level and stationary at first difference except for GDP per capita (\( y \)) which is stationary at level.

The first step in the ARDL approach is to estimate Eq. (5) for all four models (aggregate, oil, gas and electricity) by ordinary least squares (OLS) in order to test for the existence of a long-run relationship among the variables, and then conducting an F-test for joint significance of the lagged-level variables. A maximum lag of one is used in the estimation procedure on the basis of the Schwarz Bayesian Criterian (SBC), and a final ARDL model is selected when the estimated equations satisfy all of the diagnostic tests. Table 3 presents the F-statistic of the joint null hypothesis that the coefficients of the lagged level variables are zero for all four different models.

The bounds F-test for cointegration yields evidence of a long-term relationship among per capita carbon emissions, per capita energy consumption and per capita income at the 5 percent level of significance for all four models. The calculated F-statistics are higher than the appropriate upper-bound critical values. This result implies that the null hypothesis of no long-term relationship can be rejected. The estimated long-term and short-term elasticities are reported in Tables 4 and 5 in panels A and B, respectively.

The long-term and short-term elasticity estimates of per capita emissions with respect to per capita income are positive and statistically significant for three of the four models. However, the long- and short-term income elasticities of the gas model are negative and statistically significant. The long-term income elasticity estimates of per capita carbon emissions are higher than the short-term income elasticity estimates of carbon emissions for the total energy, oil and electricity models. This result indicates that there is a monotonic increasing relationship between carbon emissions and per capita income in Saudi Arabia for these three models. Two interesting results emerge from the empirical findings of this study. First, the long-term income elasticity is greater than the short-term income elasticity, implying that income leads to greater \( CO_2 \) emissions in Saudi Arabia. This result is not surprising because Saudi Arabia is an oil-based economy encompassing energy-intensive industries with energy-intensive lifestyles in the building and transportation sectors; most importantly, energy prices are highly subsidized in the country. A monotonically increasing relationship between environmental degradation and economic growth demands strict environmental regulations and even limits on economic growth to ensure a sustainable scale of economic activity within an environmentally friendly atmosphere.

Second, the long- and short-term income elasticities of carbon emissions are negative for the gas model. This result indicates that carbon emissions can be reduced with rising per capita income if the Saudi Arabian economy switches from oil consumption to gas consumption.

The long- and short-term elasticity estimates of per capita emissions with respect to all sources of energy (both aggregate and disaggregate) are positive and statistically significant. This positive and statistically significant relationship between carbon emissions and different sources of energy consumption indicate that an increase in per capita energy consumption leads to an increase in per capita carbon emissions. Interestingly, the long- and short-term elasticity estimates of per capita carbon emissions with respect to per capita electricity consumption are less than the long- and short-term elasticity estimates of carbon emissions with respect to aggregate energy, oil and gas. Therefore, it can be concluded that electricity is less polluting than other sources of energy.

The next step involves estimating the VECM and Granger causality test as described by Eqs. (8)–(10). The existence of a cointegration relationship among the variables, as shown by the cointegration statistics in Table 2, indicates that there is Granger causality in these variables, at least in one direction, but it does not

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\(^1\) Detailed discussion on Zivot–Andrews structural break test is given by Sen (2003). Following Shahbaz et al. (2013b), we used Model (C) for empirical estimation.
Table 3: ARDL cointegration test.

<table>
<thead>
<tr>
<th>Estimated model</th>
<th>Total energy consumption</th>
<th>Petroleum consumption</th>
<th>Gas consumption</th>
<th>Electricity consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>F-test for cointegration</td>
<td>5.67**</td>
<td>6.85**</td>
<td>6.12**</td>
<td>8.21**</td>
</tr>
<tr>
<td>Pesaran et al. (2001) critical values</td>
<td>1% levela</td>
<td>5% levela</td>
<td>10% levela</td>
<td>5% levelb</td>
</tr>
<tr>
<td>Lower bounds</td>
<td>1.5</td>
<td>3.79</td>
<td>3.17</td>
<td>2.72</td>
</tr>
<tr>
<td>Upper bounds</td>
<td>6.36</td>
<td>4.85</td>
<td>4.14</td>
<td>3.83</td>
</tr>
<tr>
<td>Narayan (2005) critical values</td>
<td>1.813</td>
<td>4.267</td>
<td>3.437</td>
<td></td>
</tr>
<tr>
<td>Lower bounds</td>
<td>7.878</td>
<td>5.473</td>
<td>4.470</td>
<td></td>
</tr>
<tr>
<td>Diagnostic tests</td>
<td>R²</td>
<td>0.859</td>
<td>0.986</td>
<td>0.997</td>
</tr>
<tr>
<td>Adjusted R²</td>
<td>0.844</td>
<td>0.982</td>
<td>0.996</td>
<td></td>
</tr>
<tr>
<td>DW</td>
<td>1.89</td>
<td>1.75</td>
<td>1.68</td>
<td>2.13</td>
</tr>
</tbody>
</table>

Notes: a Unrestricted intercept and no trend. b No intercept and no trend. ** Indicates the rejection of null hypothesis no cointegration at 1% significance level.

Table 4: Estimated coefficients.

<table>
<thead>
<tr>
<th>Sector/variables</th>
<th>Total energy consumption</th>
<th>Petroleum consumption</th>
<th>Gas consumption</th>
<th>Electricity consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panel A: Long-term elasticities</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>yᵣ</td>
<td>0.45 (3.30)</td>
<td>0.56 (1.59)</td>
<td>−0.41 (−9.16)</td>
<td>0.24 (2.56)</td>
</tr>
<tr>
<td>et</td>
<td>0.82 (7.37)</td>
<td>1.10 (2.94)</td>
<td>1.17 (13.03)</td>
<td>0.62 (40.33)</td>
</tr>
<tr>
<td>Constant</td>
<td>−5.93 (−4.26)</td>
<td>−7.61 (−1.81)</td>
<td></td>
<td>−5.57 (−6.14)</td>
</tr>
<tr>
<td>Panel B: Short-term elasticities</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Δyᵣ</td>
<td>0.20 (1.99)</td>
<td>0.13 (1.82)</td>
<td>−0.69 (−2.41)</td>
<td>0.14 (3.13)</td>
</tr>
<tr>
<td>Δet</td>
<td>−0.39 (−2.08)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Δecm</td>
<td>0.36 (5.05)</td>
<td>0.25 (3.12)</td>
<td>0.82 (8.66)</td>
<td>0.36 (5.57)</td>
</tr>
<tr>
<td>Constant</td>
<td>−2.62 (−2.62)</td>
<td>−1.76 (−2.33)</td>
<td>−3.25 (−6.03)</td>
<td></td>
</tr>
<tr>
<td>ECM₋₁</td>
<td>−0.23 (−2.41)</td>
<td>−0.59 (−6.58)</td>
<td>−0.58 (−5.70)</td>
<td></td>
</tr>
<tr>
<td>Panel C: Diagnostic tests</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>χ²H₀(2)</td>
<td>0.09 [0.769]</td>
<td>1.09 [0.304]</td>
<td>4.53 [0.051]</td>
<td>2.42 [0.129]</td>
</tr>
<tr>
<td>χ²H₀(2)</td>
<td>1.89 [0.387]</td>
<td>0.01 [0.994]</td>
<td>1.52 [0.468]</td>
<td>0.41 [0.813]</td>
</tr>
<tr>
<td>χ²H₀(1)</td>
<td>0.40 [0.533]</td>
<td>0.17 [0.678]</td>
<td>0.32 [0.573]</td>
<td>2.69 [0.109]</td>
</tr>
<tr>
<td>χ²H₀(1)</td>
<td>0.05 [0.819]</td>
<td>2.28 [0.143]</td>
<td>0.13 [0.724]</td>
<td>0.56 [0.461]</td>
</tr>
</tbody>
</table>

Note: *Values are given in parentheses, and p-values are given in brackets. χ²H₀(2) is the Lagrange multiplier test of residual serial correlation; χ²H₀(2) is the Jarque-Bera test of normality based on a test of skewness and kurtosis of the residual; χ²H₀(1) is a heteroskedasticity test based on the regression of squared residuals on squared fitted values; and χ²H₀(1) is Ramsey’s RESET test using the square of the fitted values for the functional form.

indicate in which direction. Table 3 shows the results of error correction-based Granger causality tests, which are the short term, long term, and combined short and long term. The results of the causality tests within the framework of VECM reveal that there are mutual causal relationships among CO₂ emissions, energy consumption and economic growth in Saudi Arabia.

4.1. These results can be summarized as follows

There is evidence of short-term bidirectional causality between CO₂ emissions and per capita income in Saudi Arabia for the aggregate model. However, we find unidirectional causality from per capita income to CO₂ emissions for the oil consumption model. Similarly, there is unidirectional causality from CO₂ emissions to per capita income for the gas consumption model. Between CO₂ emissions and energy consumption (aggregate, oil, gas and electricity), there is a bidirectional causality in both the short and long term. Granger causality does not exist between per capita electricity consumption and GDP per capita; hence, it can be concluded that the neutrality hypothesis holds in this case.

A Wald test is used to test for the joint significance of short- and long-term effects; the results are reported in the last three columns of Table 3. The joint short- and long-term causality (strong Granger causality) test result shows that there is a bidirectional causal relationship between energy consumption and economic growth. For the aggregate energy consumption model, per capita income, energy consumption and the error correction term are jointly significant in the CO₂ emissions equations. Similarly, CO₂ emissions, energy consumption and the error correction term are jointly significant in the per capita income equation. In the per capita energy consumption equation, per capita income, CO₂ and the error correction term are also
Table 5
Granger causality test results.

<table>
<thead>
<tr>
<th>The variables below are Granger-caused by the variables on the right</th>
<th>Short-term $r^2$ statistic</th>
<th>Long-term $r$ statistic</th>
<th>Joint short- and long-term effects $r^2$ statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\Delta \gamma$</td>
<td>$\Delta \alpha$</td>
<td>$\Delta \gamma$</td>
</tr>
<tr>
<td>Total energy consumption</td>
<td>3.72 (0.053)</td>
<td>30.82 (0.000)</td>
<td>−4.19 (0.000)</td>
</tr>
<tr>
<td>Petroleum consumption</td>
<td>3.29 (0.069)</td>
<td>9.73 (0.002)</td>
<td>−2.41 (0.023)</td>
</tr>
<tr>
<td>Gas consumption</td>
<td>0.00 (0.00)</td>
<td>0.00 (0.00)</td>
<td>0.00 (0.00)</td>
</tr>
<tr>
<td>Electricity consumption</td>
<td>3.69 (0.055)</td>
<td>9.46 (0.002)</td>
<td>−0.06 (0.949)</td>
</tr>
</tbody>
</table>

p-Values are in parentheses.

The results of the dynamic linkage between energy consumption (aggregate, oil, gas and electricity) and economic growth show that a sustainable energy supply is indispensable for economic growth. The strong dynamic causality results indicate that energy consumption leads to economic growth in Saudi Arabia in the long term. The results also show that aggregate and disaggregate energy consumption leads to an increase in carbon emissions both in the short and long term. This result indicates that an increase in energy consumption could result in a deterioration of environmental quality by increasing the carbon emissions in the country. However, electricity is a less polluting source of energy compared with other sources of energy, such as oil and gas.

The detrimental effect of declining environmental quality in the country could affect human health, agricultural productivity, water resources and ultimately economic growth. Therefore, it is important for policy makers to develop strategic plans to reduce carbon emissions to protect the environment for future generations. One important suggestion is that because energy prices are heavily subsidized by the Saudi government and because these energy price distortions are primarily responsible for the implausibly high energy intensity in the country, the Saudi government can effectively implement an energy conservation policy through energy price reforms and fuel substitution. With increased energy prices, consumers/producers would decrease their consumption of energy; thus, more energy-efficient technology would be used, which would result in less CO2 emissions.

5. Conclusions

The objective of this study is to examine the relationships among economic growth, carbon emissions and energy consumption at the aggregate and disaggregate levels for Saudi Arabia over the 1980–2011 period. The empirical estimates of this study provide an important policy implication for Saudi Arabia. The estimated long-term income elasticities of carbon emissions in three of the four models are higher than the estimated short-term income elasticities of carbon emissions, which imply that over time, per capita carbon emissions increase with the rise in per capita incomes in Saudi Arabia. This result indicates that there is a monotonic increasing relationship between carbon emissions and per capita income in Saudi Arabia. Therefore, the EKC hypothesis does not hold for these three models. A monotonic increasing relationship between environmental degradation and economic growth demands strict environmental regulations and even limits on economic growth to ensure a sustainable scale of economic activity within an environmentally friendly atmosphere. The other important finding of this study is that the long- and short-term income elasticities of carbon emissions are positive for the aggregate, oil and electricity models, but these elasticities are negative for the gas consumption model. This result implies that if the Saudi Arabian economy switches from oil to gas consumption, then carbon emissions can be reduced when per capita income increases.

References
