



# Carbon dioxide emissions, economic growth, energy use, and urbanization in Saudi Arabia: evidence from the ARDL approach and impulse saturation break tests

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## Abstract

This study investigates the existence of long-run relationship between CO<sub>2</sub> emissions, economic growth, energy use, and urbanization in Saudi Arabia over the period 1971–2014. The autoregressive distributed lag (ARDL) approach with structural breaks, where structural breaks are identified with the recently impulse saturation break tests, is applied to conduct the analysis. The bounds test result supports the existence of long-run relationship among the variables. The existence of environmental Kuznets curve (EKC) hypothesis has also been tested. The results reveal the non-validity of the EKC hypothesis for Saudi Arabia as the relationship between GDP and pollution is positive in both the short and the long run. Moreover, energy use increases pollution both in short and long run in the country. On the contrary, the results show a negative and significant impact of urbanization on carbon emissions in Saudi Arabia, which means that urban development is not an obstacle to the improvement of environmental quality. Consequently, policy-makers in Saudi Arabia should consider the efficiency enhancement, frugality in energy consumption, and especially increase the share of renewable energies in the total energy mix.

**Keywords** CO<sub>2</sub> emissions · Economic growth · Energy use · Urbanization · Environmental Kuznets curve  
Impulse saturation break tests · Saudi Arabia

## Introduction

In recent decades, there has been a growing concern about the pollution of environment and climate as they pose serious threats to people's health and to the environment across the world. With this growing interest, there is a pressure on countries to achieve a sustainable development, on which the well-being of current and future generations relies. According to the Intergovernmental Panel on Climate

Change (IPCC) (2013), “greenhouse gases related to human activities are the most significant driver of observed climate change since the mid-20th century.” These greenhouse gas emissions are responsible for the increased average temperature of the earth. Carbon dioxide (CO<sub>2</sub>) is the most pollutant among the greenhouse gases (Baek and Pride 2014); it is the source of more than 60% of the world's greenhouse effect.

Factors like economic growth, energy consumption, urbanization, the threats of pollution, and climate change have amplified. Consequently, countries should coordinate economic development with environmental protection and climate change mitigation. The theoretical framework defining the relationship between economic growth and environmental quality can be formulated as follows: during the early stage of economic development, degradation and pollution increase. However, after a specific level, rise in economic growth reduces environmental pressure and, therefore, environmental quality ameliorates. This relationship firstly introduced by Grossman and Krueger (1991) is called the environmental Kuznets curve (EKC). It refers to the existence of an inverted U-shaped relationship between economic growth and environmental quality. In the case of its validity,

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economic growth itself is the solution for clean environment (Ahmad et al. 2017).

This paper examines the relationship between carbon dioxide (CO<sub>2</sub>) emissions, economic growth, energy use, and urbanization in Saudi Arabia. The choice of Saudi Arabia is driven by, at least, three motivations. First, Saudi Arabia is a major player in the world's energy markets. It is the world's leading oil producer and exporter and its economy is heavily based on the production and the exportation of fossil fuels; these are known to be one of the culprits of climate change and pollution. With over 266.6 billion barrels of proven oil reserves, KSA accounts for more than 16% of the global proven reserves (BP statistical review of world energy, 2016). The oil sector in Saudi Arabia accounts for 47% of GDP, 90% of revenues, and 90% of export earnings.<sup>1</sup> Second, the country is entirely dependent on fossil fuel consumption. Particularly, over the recent decades, Saudi Arabia has experienced a fast-growing demand for oil and its derivatives, gas, and gas liquids. For instance, the country's oil consumption has witnessed an all-time increase from 441 thousand b/day in 1971 to 3.726 million b/day in 2014 (BP statistical review of world energy, 2015). Saudi Arabia is now the world's sixth<sup>2</sup> largest oil consumer, behind the USA, China, India, Japan, and Russia. Its consumption is nowadays more than one-fourth of production. If this increase remains, it will have major implications on Saudi oil production and exports (Gately et al. 2012). According to the Saudi Arabia's Energy Efficiency Report (January 2011), energy consumption is growing more rapidly than GDP. High domestic consumption is particularly due to population growth, rapid industrial and economic growth, and the existence of subsidized energy prices that encourage over-consumption (Fattouh and El-Katiri 2013). However, it also leads to high carbon emissions, which may harmfully affect the environment, especially if it is accompanied by inefficiency. Finally, our third motivation is linked to the investigation of the effect urbanization on CO<sub>2</sub> emissions. In particular, Saudi Arabia has enjoyed a quite rapid rate of urbanization over the past few decades. This process may lead to a rise in environmental and ecological impacts and increase pressure on the country's natural resources. Therefore, it is important to investigate the effect of urbanization on the quality of the environment.

The country's rapid economic development made the country face serious environmental challenges that emerge from the high speed of population growth, the increase in the demand for energy, and the fast-paced urban development accompanied by high level of CO<sub>2</sub> emissions. Accordingly, investigating the relationship between CO<sub>2</sub> emissions,

economic growth, energy use, and urbanization is a topic of great importance for the country.

In this paper, we contribute to the existing literature by investigating the relationships between CO<sub>2</sub> emissions, economic growth, energy use, and urbanization in Saudi Arabia. Specifically, we apply the autoregressive distributed lag (ARDL) bounds testing approach, with breaks, to cointegration, over 1971–2014 period, for this purpose. To the best of my knowledge, no previous study incorporated simultaneously the four variables—CO<sub>2</sub> emissions, economic growth, energy use, and urbanization—in the case of Saudi Arabia. Moreover, within this context, our study is the first that examines the EKC hypothesis for Saudi Arabia by using the ARDL model, while taking potential structural breaks into account. More importantly, the potential breaks were identified by the recently impulse indicator saturation (IIS) method, which is suitable for small sample sizes. Finally, our study tries to further enrich the analysis of the relation between economic activity and environmental quality relative to the oil-exporting countries since only little research has been done on the subject.

The remainder of the paper is organized as follows: the “Literature review” section presents a summary of the literature. The “Methodology and data” section outlines the methodology and data. Results and discussions are presented in the “Results and discussions” section and the “Conclusion and policy implications” section provides conclusions and policy implications.

## Literature review

There is a growing literature that focuses on the relationship among economic growth, energy consumption, urbanization, and environmental quality. The main existing studies can be classified into four groups.

The first group of the literature concentrates on the environmental pollution and economic growth nexus. This group focuses on the validity of the EKC hypothesis, which postulates that during the early stages of economic growth, environmental quality declines with the increment in per capita income, but after a certain level, quality begins to ameliorate. This relationship means that the environmental impact variable is an inverted U-shaped function of per capita income. There have been many studies on this topic but there is no overall consensus regarding the validity of EKC hypothesis. For instance, Apergis and Payne (2010), Hamit-Hagggar (2012), Babu and Datta (2013), Shahbaz et al. (2013a), and Apergis and Ozturk (2015) argued the existence of the EKC hypothesis. However, the hypothesis was not retained by many other researchers such as Coondoo and Dinda (2008), Begum et al. (2015), Lacheheb et al. (2015) and Al-Mulali et al. (2015b). Readers interested in a more extensive review

<sup>1</sup> Saudi Arabia Monetary Agency (2014): Forty Nineth Annual Report, Government of Saudi Arabia. Available at <http://www.sama.gov.sa/sites/SAMAEN/ReportsStatistics/Pages/AnnualReport.aspx>.

<sup>2</sup> <https://www.eia.gov/tools/faqs/faq.php?id=40&t=6>

of EKC literature may consult various papers such as Stern (2004) and Kijima et al. (2010).

The second group focuses on the relationship between the energy consumption and output nexus. Several publications, using the Granger causality test as well as the cointegration approach, have appeared in recent years documenting the relationship between economic growth and energy consumption. The overview of these empirical studies shows conflicting results that can be classified depending on four alternative hypotheses: the feedback hypothesis, the growth hypothesis, the neutrality hypothesis, and the conservation hypothesis (e.g., Magazzino 2016). Among others, Soytaş and Sari (2003), Oh and Lee (2004), and Narayan and Smyth (2008), who showed the existence of unidirectional causality from energy consumption to economic growth, approve the growth hypothesis. The conservation hypothesis, describing unidirectional causality from economic growth to energy consumption, was found by several works such as Asghar (2008), Sari et al. (2008), and Dhungel (2008). The bidirectional causality between economic growth and energy consumption, known as the feedback hypothesis, has been provided by various studies such as Ghali and El-Sakka (2004), Lee (2006), Lee and Chang (2007), and Shahbaz and Lean (2012). The final hypothesis, known as the neutrality hypothesis, signifies that no causal relationship exists among economic growth and energy consumption. The findings of the neutrality hypothesis are supported by Cheng (1995), Jobert and Karanfil (2007), and Payne (2009), among others.

The third group of empirical studies extends the previous works by examining the dynamic relationships among carbon dioxide, output, and energy consumption. Research on this topic has been prolific, e.g., Soytaş et al. (2007), Halicioğlu (2009), Zhang and Cheng (2009), Narayan and Narayan (2010), Nasir and Rehman (2011), Alam et al. (2012), Hamit-Haggar (2012), Shahbaz et al. (2013b), Tiwari et al. (2013), Farhani et al. (2014), and Amri (2017), among others. These studies focus not only on the validity of EKC hypothesis, but also to the potential relationship among all the variables including the short-run and the long-run relationship, as well as the existence of causality relationship. The overview of these studies does not show any consensus regarding their findings. For example, Soytaş et al. (2007) analyzed the effect of energy consumption and output on carbon emissions in the USA. The authors found that income does not Granger cause CO<sub>2</sub> emissions in the USA in the long run, however energy use does. Their main conclusion suggests that income growth by itself may not become a solution to environmental issues. Similarly, Narayan and Narayan (2010) explored the existence of EKC hypothesis for a panel of developing countries and found that for almost 35% of the sample CO<sub>2</sub> emissions have fallen, over the long run, with the rise in economic growth. Likewise, Tiwari et al. (2013) confirmed the validity of the EKC hypothesis. They showed that coal consumption and

trade openness contribute to CO<sub>2</sub> emissions. They also reported a bidirectional relationship between economic growth and CO<sub>2</sub> emissions and between coal consumption and CO<sub>2</sub> emissions. However, only unidirectional relations were found from trade openness to economic growth, coal consumption, and CO<sub>2</sub> emissions. Also, Shahbaz et al. (2013b) used the ARDL specification in the presence of structural breaks, to study the relationship between some economic and financial variables and CO<sub>2</sub> emissions. They come to the conclusion that economic growth and energy consumption increase CO<sub>2</sub> emissions, but financial development and trade openness decrease the emissions. More recently, Amri (2017) explored the relationship between CO<sub>2</sub> emissions, income, and non-renewable and renewable energy consumption, using Algerian data from 1980 to 2011. He recognized that non-renewable energy increases CO<sub>2</sub> emissions, while an insignificant effect has been reported for the renewable energy. He also concluded to the validity of EKC hypothesis for Algeria.

The last group of literature includes the urbanization into the nexus as a variable that may explain CO<sub>2</sub> emissions. In recent years, empirical studies have become increasingly interested in the effect of urbanization on environmental quality. However, researchers found mixed results regarding the effects of urbanization. For example, Martínez-Zarzoso and Maruotti (2011) made use of an extended version of the STIRPAT<sup>3</sup> model to explore the relationship between urbanization and CO<sub>2</sub> emissions in developing countries, over the period 1975–2003. They came to the conclusion that an inverted U-shaped relationship exists between urbanization and carbon emissions. They also found, after classifying the countries into three homogeneous groups, that the relationship between emission and urbanization for two of them became negative behind a certain level of urbanization. Though, for the third group, solely population and wealth lead to CO<sub>2</sub> emissions, but no evidence found for urbanization. Similarly, Sadorsky (2014) analyzed the effect of urbanization on CO<sub>2</sub> emissions relative to a sample of emerging countries, using dynamic heterogeneous panel regression techniques. The author's results showed that the urbanization variable does not have statistically significant effect on CO<sub>2</sub> emissions for most of the cases. Also, Wang et al. (2016a) explored the relationship between urbanization, energy use, and CO<sub>2</sub> emissions, using panel cointegration and Granger causality test for Association of Southeast Asian Nations. The empirical results indicate short-run causal relationships from urbanization to energy use and from urbanization to CO<sub>2</sub> emissions. Likewise, the results show that in the long term, both urbanization and energy use result in carbon emissions. More recently, Wang et al. (2016b) examined the impacts of economic growth and urbanization on sulfur dioxide

<sup>3</sup> STIRPART Stochastic Impacts by Regression on Population, Affluence, and Technology.

emissions. Their findings revealed the existence of an inverted U-shaped curve relationship between economic growth and sulfur dioxide emissions and between urbanization and emissions. Also, Shahbaz et al. (2016) investigated the impact of urbanization on CO<sub>2</sub> emissions in the case of Malaysia over the period of 1970 Q1–2011 Q4. Their main results conclude the existence of U-shaped relationship between urbanization and CO<sub>2</sub> emissions, in the sense that at early stage, urbanization decreases CO<sub>2</sub> emissions, but after a certain level, it increases CO<sub>2</sub> emissions. Further, the Granger causality analysis suggests unidirectional relationship from urbanization to CO<sub>2</sub> emissions. Similarly, Saidi and Mbarek (2017) studied the impact of urbanization on carbon dioxide emissions for a panel of emerging economies over the period 1990–2013. They found that urbanization decreases the CO<sub>2</sub> emissions. Using the ARDL approach, Ali et al. (2017) investigated the impact of urbanization on carbon dioxide emissions in Singapore over the period 1970–2015. The obtained result reveals a negative and significant impact of urbanization on carbon emissions in Singapore. Their findings showed that urbanization is not a barrier to the amelioration of environmental quality in Singapore. In a different application that involves electricity consumption conducted on United Arab Emirates, Sbia et al. (2017) concluded to the existence of an inverted U-shaped relationship between urbanization and electricity consumption, which means that urbanization increases electricity consumption initially and, after a certain level of urbanization, electricity demand decreases. Further, economic growth and urbanization Granger cause each other. The feedback hypothesis is also found between urbanization and financial development, and financial development and economic growth, and the same is true for electricity consumption and urbanization.

Regarding Saudi Arabia, there exist some papers that examined the dynamic relationships among economic growth, energy consumption, and environmental quality (see Table 8, on appendix). The first type of studies used a panel cointegration test to investigate the dynamic causal relationships between energy consumption and economic growth in Saudi Arabia included either in the GCC<sup>4</sup> group, in the OPEC<sup>5</sup> group, or the in MENA<sup>6</sup> group. Among others, we can cite Al-Iriani (2006) who studied the causal relationship between energy consumption and economic growth in the six GCC members using panel cointegration and panel generalized method of moments (GMM) estimator to test for Granger causality. Similarly, based on the same methodology, Mehrara (2007) studies the causal relationship relative to a sample of selected oil-exporting countries. Both authors found

unidirectional causality from economic growth to energy consumption. Also, Arouri et al. (2012) studied the relationship between economic growth and CO<sub>2</sub> emissions in the MENA region over the period 1981–2005. They recognized that EKC hypothesis is not valid at the country level, but valid at the regional level. Recently, Al-Mulali and Ozturk (2015) reported that energy consumption, urbanization, trade openness, industrial output, and political stability variables have short-run and long-run causal relationship with the ecological footprint. More recently, Hassine and Harrathi (2017) explored the relationship between renewable energy consumption, real gross domestic product, trade, and financial development (FD) for the GCC countries over the period 1980–2012. The main results reveal no evidence of causality in the short run neither between output and renewable energy consumption nor between exports and renewable energy consumption. Furthermore, renewable energy use and exports are found able to increase the economic growth.

The second type of literature focuses directly on the analysis of relationships among energy consumption, economic growth, and environmental quality or on the validity of EKC hypothesis in Saudi Arabia. For example, Alkhatlan and Javid (2013) performed an ARDL approach in order to explore the relationship among energy consumption, carbon emission, and economic growth taken at aggregate and disaggregate (oil, gas, and electricity) levels for Saudi Arabia. The findings showed a positive long-run relationship between electricity consumption and carbon emissions. Additionally, they found the same relationship between per capita GDP and carbon emissions; however, no causality between per capita electricity consumption and per capita GDP was detected. In a paper that appeared in 2014, Alshehry and Belloumi (2014) focused on the analysis of relationship between fossil fuel consumption and economic growth in Saudi Arabia. The authors concluded the existence of unidirectional causality from economic growth to energy consumption in the long run and absence of causality in the short run. Using Gregory and Hansen (1996) cointegration procedure and ECM, Banafea (2014) showed the existence of causal relationship between real GDP and oil consumption in both the short and long run. Recently, Alshehry and Belloumi (2015) used a Johansen multivariate cointegration approach to examine dynamic causal relationships between energy consumption, energy prices, and economic growth, employing carbon emissions as a control variable. The authors explored a unidirectional causality in both the short and the long run, between energy consumption and economic growth in Saudi Arabia. Similarly, Mezghani and Ben Haddad (2017) used the time-varying parameters vector autoregressive (TVP-VAR) model with stochastic volatility to investigate inter-temporal dynamics between Saudi Arabian real GDP (oil, non-oil), electricity consumption, and CO<sub>2</sub> emissions levels for 1971–2010. Their findings showed that the observed high volatility

<sup>4</sup> Gulf Cooperation Council is a regional intergovernmental union consisting of Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates

<sup>5</sup> Organization of the Petroleum Exporting Countries

<sup>6</sup> Middle East and North Africa countries

of electricity consumption in the 1970s and 1980s is likely to have persistent negative effects on oil GDP levels and CO<sub>2</sub> emissions and positive effects on real non-oil GDP levels. The observed high and low volatility of oil GDP levels positively affects electricity consumption and CO<sub>2</sub> emissions. However, highly volatile non-oil GDP levels are likely to affect electricity consumption and CO<sub>2</sub> emissions positively. The authors concluded that energy policies must consider high- and low-volatility regimes of real GDP, electricity, and CO<sub>2</sub> emission shocks and time-varying patterns of the relationships between real GDP, electricity consumption, and CO<sub>2</sub> emissions. The studies concerning the validity of the EKC hypothesis in Saudi Arabia are limited. Among these studies, the work performed by Taher and Hajjar (2014) and Samargandi (2017) who reported no evidence of the EKC hypothesis. However, their results opposed with the findings of Mahmood and Alkhateeb (2017).

This research aims to extend the fourth group of research and investigates dynamic relationship between carbon emissions, energy use, economic growth, and urbanization. Little research has been done based on the above variables, and particularly, there is no study (see Table 8, for a summary) that has assessed the relationship among the considered variables in Saudi Arabia.

## Methodology and data

### Methodology

This section outlines the fundamental techniques adopted in the study. Three main steps are implemented in our paper. First, we begin by examining the integration proprieties of the variables under consideration. For that, unit root tests with and without breaks were performed to each variable. This step is necessary in order to check that none of them is  $I(2)$ . Having this in hand, we are [on the right path](#), and therefore we can employ the ARDL model specification to investigate the existence or absence of cointegration relationship between CO<sub>2</sub> emissions and the other variables. However, before proceeding to ARDL model specification, we complete our investigation by applying the novelty approach on multiple change detection, the impulse indicator saturation (IIS) method (Hendry et al. 2008; Johansen and Nielsen 2009; Hendry and Santos 2010) in order to detect any potential structural breaks in the dependent variable. In a third step, and if significant structural changes have occurred, they should be picked up by the analysis, and consequently, an ARDL model with structural break impacts is built.

The EKC hypothesis stipulates that economic development deteriorates environment before improving it, hence resulting in an inverted U-shaped curve. The standard EKC formulation advocates that the environmental degradation depends on

GDP and the square of GDP. However, due to the multicollinearity<sup>7</sup> that may adversely affect the regression results, Narayan and Narayan (2010) proposed an alternative<sup>8</sup> approach to examine whether carbon dioxide emissions decline over time with the increase of the economic growth.

The proposed approach consists in comparing the short-run elasticity with the long-run one. According to Narayan and Narayan (2010), if the long-run income elasticity is less than the short-run income elasticity, it can be concluded that, over time, further income will lead to less carbon dioxide emissions. However, the EKC requires a negative relationship after certain income level. If long-run elasticity is inferior to short-run elasticity but still has a positive value, it signifies that the emissions are still harmful for the environment but with a declining trend. To investigate the existence of the EKC hypothesis, the long-run elasticity should be negative. As showed by Narayan and Narayan (2010), “a negative effect of income on emissions in the long-run is consistent with the EKC.”

Following Narayan and Narayan (2010), the general form of the model can be written as:

$$CO2_t = f(GDP_t, EU_t, URB_t) \quad (1)$$

where CO<sub>2t</sub> denotes the carbon dioxide (CO<sub>2</sub>) emission (metric tons per capita), EU<sub>t</sub> is the energy use (metric tons per capita), GDP<sub>t</sub> denotes the economic growth (real GDP per capita in US dollars 2010), and URB<sub>t</sub> denotes urbanization (the % population in urban agglomerations of more than 1 million). We further transform the functional form of the model (Eq. 1), we obtain the following model:

$$\text{LnCO}_2_t = \alpha_0 + \alpha_1 \text{LnGDP}_t + \alpha_2 \text{LnEU}_t + \alpha_3 \text{LnURB}_t + v_t \quad (2)$$

where Ln denotes the natural logarithm and  $\alpha_i$  ( $i = 1, \dots, 4$ ) denotes the parameters of the model.

This study applied the ARDL-bound testing approach to cointegration in order to test the presence of cointegration among the variables and to estimate the long-run and short-run elasticities of the variables.

Appealing features of the ARDL approach have made convincing arguments for its use in our modeling strategy. The main advantage lies in its flexibility, compared to other cointegration approaches such as the Johansen cointegration techniques that it can be applied whether the variables involved are purely stationary  $I(0)$  or difference stationary  $I(1)$ , a mixed or mutually cointegrated. Further, the approach can be applied even in studies

<sup>7</sup> Multicollinearity exists when two or more of the independent variables in a regression model are highly correlated.

<sup>8</sup> In a recent paper, Narayan et al. (2016) proposed a different method to testing EKC hypothesis, based on cross-correlation: EKC exists if there is a positive cross-correlation between the current level of income and the past level of CO<sub>2</sub> emissions and a negative cross-correlation between the current level of income and the future CO<sub>2</sub> emissions.

with small sample size (Pesaran et al. 2001). Besides, the ARDL approach can estimate the long-run and short-run parameters of the model simultaneously.

The practical implementation of the ARDL requires two stages. The first stage consists testing for the existence of a long-run relationship, which is based on the *F* test, between the relevant variables in the context of an error correction framework. The asymptotic distribution for this *F* test is however non-standard. Consequently, two sets of asymptotic critical values are reported by Pesaran and Pesaran (1997): an upper bound assuming that all the regressors are I(1) and a lower bound assuming that all the regressors are I(0). There is evidence for cointegration that a long-run relationship exists between the variables, if the computed *F* statistic exceeds the upper critical value. The test is inconclusive, if the *F* statistic falls between the lower and upper critical values. However, if the *F* statistic is less than the lower critical value, no cointegration relationship exists between the variables.

The second stage of the ARDL approach is to estimate the coefficients of the long-run relations and make inferences about their value. This step is valid only if the *F* tests in the first stage do not reject the existence of a long-run relationship between the variables.

Thus, the error correction specification of the ARDL model can be expressed as:

$$\begin{aligned} \Delta \text{LnCO}_2_t = & \delta_0 + \alpha_1 D_{03} + \delta_1 \text{LnCO}_2_{t-1} + \delta_2 \text{GDP}_{t-1} + \delta_3 \text{EU}_{t-1} \quad (3) \\ & + \delta_4 \text{LnURB}_{t-1} + \sum_{i=1}^p a_i \Delta \text{LnCO}_2_t + \sum_{i=1}^q b_i \Delta \text{LnEU}_t \\ & + \sum_{i=1}^r c_i \Delta \text{LnGDP}_t + \sum_{i=1}^m d_i \Delta \text{LnU}_t + v_t \end{aligned}$$

where  $\Delta$  represents the first difference of variables,  $v_t$  represents the error term,  $\delta_0$  represents the constant coefficient,  $\delta_i$ ,  $i = 1, 2, 3, 4$  are the long-run coefficients,  $a_i$ ,  $b_i$ ,  $c_i$ , and  $d_i$  are the short-run coefficients, and  $D_{03}$  denotes a dummy variable<sup>9</sup> that represents the structural break in the dependent variable  $\text{CO}_2$  emissions and takes a value of 0 until 2002 and a value of 1 from 2003 onwards. The information on the structural break in the time series is crucial in correctly specifying the model. The model above is ARDL (p, q, r, m), where p, q, r, and m represent the lag length.

The null hypothesis of no cointegration  $\delta_1 = \delta_2 = \delta_3 = \delta_4 = 0$  was tested against the alternative hypothesis of  $\delta_1 \neq \delta_2 \neq \delta_3 \neq \delta_4 \neq 0$  in Eq. (3).

In the case of existence of cointegration relationship between the variables, we proceed to the examination of the short- and the long-run coefficients of the model in

order to examine the existence of the EKC hypothesis and the investigation of the relationship among the variables. Finally, the appropriateness and the stability of the model were checked by diagnostic tests and the plots of the cumulative sum (CUSUM) of recursive residuals and the CUSUM of square (CUSUMSQ).

## Data

This paper examined annual time series data on Saudi Arabia for the period 1971–2014. The time period was determined by the availability of a complete series for the analyzed variables. The data consist of carbon dioxide ( $\text{CO}_2$ ) emissions (metric tons per capita), energy consumption (EU) (kg of oil equivalent per capita), per capita real GDP (GDP) (constant 2010 US\$), and urbanization (URB) (measured by the % population in urban agglomerations of more than 1 million). All data are in natural logarithms. The data are extracted from World Development Indicators (WDI) online database provided by World Bank’s Development<sup>10</sup> Indicators. Figure 1 shows carbon emissions per capita, real GDP per capita, per capita energy use, and urbanization in log levels, in Saudi Arabia over the period 1971–2014. Finally, the econometric software used were EViews 9.0 and the “GETS” and “strucchange” R packages.

## Descriptive statistics

Descriptive statistics and the pair-wise correlations of the variables under consideration are reported in Table 1.

It can be seen, from the table, that energy use exhibits the highest variability over the period, as indicated by its coefficient of variations, while the GDP is the least volatile. The statistics of Jarque-Bera test demonstrate that all the variables, except GDP and LEU, are normally distributed. All the series display excess kurtosis and are negatively skewed, except for the GDP, which is positively skewed.

For the correlation analysis, we find that  $\text{CO}_2$  emissions and energy use are positively and significantly correlated, suggesting that energy use might prove useful in explaining  $\text{CO}_2$  dynamics. Positive correlation is also found between EU and urbanization. However, a negative and insignificant correlation exists between  $\text{CO}_2$  emissions and economic growth. Further, energy use is negatively correlated with GDP. The latter is found significantly and negatively linked to urbanization.

<sup>9</sup> The break date was identified by the impulse saturation break test (see the “Impulse saturation break tests for multiple breaks detection” section)

<sup>10</sup> World Bank’s WDIs. <http://databank.worldbank.org/data/home.aspx>

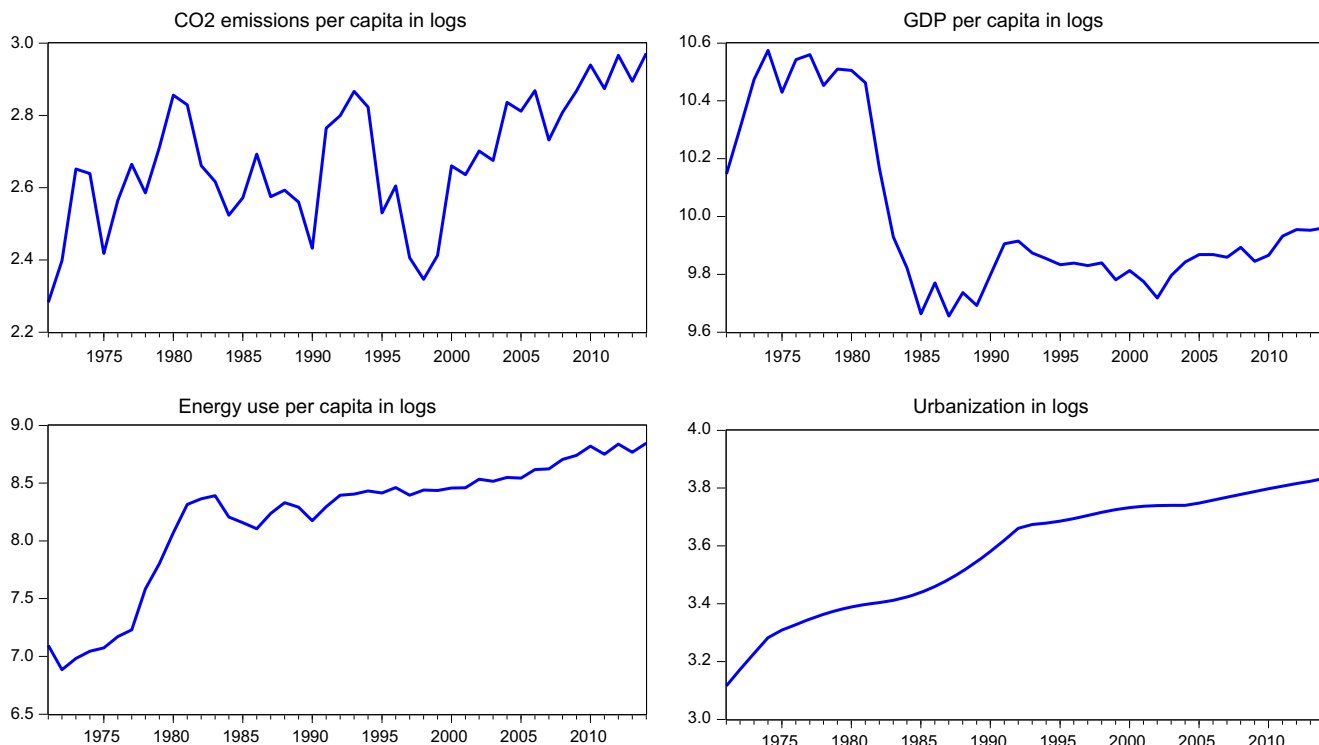


Fig. 1 Dynamics of CO<sub>2</sub> emissions per capita, real GDP per capita, per capita energy use, and urbanization in log levels, in Saudi Arabia

## Results and discussions

### Integration analysis

To check stationarity of the time series, the researcher first applied two conventional unit root tests, namely the augmented Dickey-Fuller (ADF) (Dickey and Fuller 1981) and the Phillips and Perron (1988) (PP) tests, to examine the nonstationarity of the analyzed variables. However, a major criticism of these tests is that they may suffer from power deficiency in the presence of structural breaks (Perron 1997). To overcome this shortcoming, we extend our analysis by performing the recently developed unit root test of Narayan and Popp<sup>11</sup> (2010) that endogenously determines two structural breaks in the model. The main appealing feature of this test is that it allows for structural break(s) under both the null hypotheses of the presence of unit root and the alternative of stationary series.

Narayan and Popp (2010) proposed two models allowing for two structural breaks. The first model (M1) accounts for two structural breaks in the level of the series while the second model (M2) allows for two structural breaks in the level and slope.

This test can be presented briefly as follows: Narayan and Popp (2010) defined a data-generating process of a time series

<sup>11</sup> The choice of the Narayan and Popp (2010) break test is motivated by the fact that this test chooses the break dates most accurate compared to the two existing and widely used unit root tests of Lumsdaine and Papell (1997) and Lee and Strazicich (2003). For more details, see Narayan and Popp (2013).

$y_t = d_t + u_t$  that has two components, a deterministic component ( $d_t$ ) and a stochastic component ( $u_t$ ), where  $u_t$  follows an AR (1) process.

The deterministic components of both models,  $d_t$ , are given by:

$$d_t^{M1} = \alpha + \beta t + \Psi^*(L) \left( \theta_1 DU'_{1,t} + \theta_2 DU'_{2,t} \right) \tag{4}$$

$$d_t^{M2} = \alpha + \beta t + \Psi^*(L) \left( \theta_1 DU'_{1,t} + \theta_2 DU'_{2,t} + \gamma_1 DT'_{1,t} + \gamma_2 DT'_{2,t} \right) \tag{5}$$

where  $DU'_{i,t} = 1 \left( t > T'_{B,i} \right)$ ,  $DT'_{i,t} = 1 \left( t > T'_{B,i} \right) \left( t - T'_{B,i} \right)$ ,  $i = 1, 2$ .

In these equations,  $T'_{B,i}$ ,  $i = 1, 2$  represent the true break dates. The parameters  $\theta_i$  and  $\gamma_i$  specify the magnitude of the level and slope breaks, respectively. The inclusion of  $\Psi^*$  in Eqs. (4) and (5) allows for breaks to happen slowly over time.

The test regressions can be derived from the corresponding structural model in reduced form as follows:

$$y_t^{M1} = \rho y_{t-1} + \alpha + \beta^* t + \theta_1 D \left( T'_B \right)_{1,t} + \theta_2 D \left( T'_B \right)_{2,t} + \delta_1 DU'_{1,t-1} + \delta_2 DU'_{2,t-1} + \sum_{j=1}^k \beta_j \Delta y_{t-j} + e_t \tag{6}$$

$$y_t^{M2} = \rho y_{t-1} + \alpha^* + \beta^* t + \Omega_1 D \left( T'_B \right)_{1,t} + \Omega_2 D \left( T'_B \right)_{2,t} + \delta_1^* DU'_{1,t-1} + \delta_2^* DU'_{2,t-1} + \gamma_1^* DT'_{1,t-1} + \gamma_2^* DT'_{2,t-1} + \sum_{j=1}^k \beta_j \Delta y_{t-j} + e_t \tag{7}$$

**Table 1** Descriptive statistics and correlation matrix

	LCO2	LEU	LGDP	LURB
Mean	2.67	8.20	9.99	3.57
Median	2.66	8.39	9.86	3.66
Maximum	2.97	8.84	10.57	3.83
Minimum	2.28	6.88	9.65	3.11
Std. dev.	0.17	0.56	0.28	0.20
CV	0.06	0.07	0.03	0.05
Skewness	-0.25	-1.21	0.99	-0.52
Kurtosis	2.27	3.25	2.47	2.01
Jarque-Bera	1.43	10.90	7.81	3.75
Probability	0.49	0.004	0.02	0.15
Correlation analysis				
	LCO <sub>2</sub>	LEU	LGDP	URB
LCO2	1			
LEU	0.54*** (0.00)	1		
LGDP	-0.04 (0.80)	-0.73*** (0.00)	1	
LURB	0.52*** (0.00)	0.89*** (0.00)	-0.67*** (0.00)	1

\*\*\*Rejection of the null hypothesis of absence of correlation at 1% level

The unit root null hypothesis against the stationary alternative corresponds to  $\rho = 1$  against  $\rho < 1$ , and  $t$  statistics of  $\hat{\rho}$  in Eqs. (6) and (7) are used. Critical values are generated through Monte Carlo simulations and given in Table 2 in Narayan and Popp (2010). The computed test statistic is compared with the relevant critical value: if the test statistic value is larger than the critical value, the null hypothesis of a unit root is rejected.

The results of the unit root tests are presented in Tables 2 and 3. The results of conventional unit root tests (see Table 2)

**Table 3** Narayan and Popp (2010) unit root test

Variables	Test	M1 test statistic	M2 test statistic
LCO2	Level	-4.287 (0) [1983, 1994]	-4.128 (0) [1990, 1999]
	1st difference	-7.558*** (0) [1990, 1994]	-6.373*** (2) [1990, 1998]
LEU	Level	1.469 (0) [1981, 1983]	-4.166 (0) [1983, 1989]
	1st difference	-6.477*** (2) [1981, 1986]	-5.640*** (0) [1983, 1986]
LGDP	Level	-5.961 (0) [1981, 1990]	-3.683 (0) [1981, 1985]
	1st difference	-8.134*** (0) [1981, 1985]	-7.907*** (0) [1981, 1985]
LURB	Level	-0.9171 (1) [1986, 1992]	-4.233 (1) [1987, 1992]
	1st difference	-7.85** (0) [1987, 1992]	-8.054** (0) [1984, 1992]

The numbers inside square brackets are the break dates. The numbers inside parentheses are the lag levels. For M1, critical value for 1% level of significance -5.259 and -4.514, respectively. For M2, critical values for 5 and 10% levels of significance are -5.949 and -5.181, respectively. Critical values are taken from Narayan and Popp (2010), Table 2

\*\*Rejection of the null hypothesis at 1% level

\*Rejection of the null hypothesis at 5% level

reveal that all the series are non-stationary at the level, but when first difference is performed, they become stationary.

The results of the Narayan and Popp (2010) unit root tests, given in Table 3, approve the previous result obtained with the conventional tests: all the variables are found to be non-stationary at level but integrated at the first difference. Both types of tests confirm that all the variables are integrated

**Table 2** Conventional unit root test results

Variables	Test	ADF		PP	
		$t$ statistic	Intercept	$t$ statistic	Intercept and trend
LCO2	Level	-2.86 (0)	-3.30 (0)	-2.86 (1)	-3.35 (1)
	1st difference	-7.13** (0)	-7.04** (0)	-7.65*** (5)	-7.52** (5)
LEU	Level	-1.75 (0)	-3.15 (2)	-1.67 (2)	-1.65 (2)
	1st difference	-5.05*** (0)	-5.41* (0)	-5.05*** (1)	-5.42** (1)
LGDP	Level	-2.36 (2)	-1.94 (2)	-1.42 (3)	-1.68 (3)
	1st difference	-5.08** (0)	-5.09** (0)	-5.06** (2)	-5.05** (2)
LURB	Level	-1.85 (2)	-1.58 (1)	-2.23 (4)	-2.25 (4)
	1st difference	-3.56** (1)	-3.47** (1)	-5.03** (1)	-5.18** (0)

The numbers inside brackets are the optimum lag lengths determined using the SIC criterion, whereas the Bartlett with Newey-West bandwidth is used for PP

\*\*Rejection of the null hypothesis at 5% level

\*Rejection of the null hypothesis at 10% level



at  $I(1)$ , so that the ARDL approach is an appropriate technique to use for the cointegration analysis (Pesaran et al. 2001).

### Impulse saturation break tests for multiple breaks detection

In order to detect potential structural changes in the  $\text{CO}_2$  emissions dynamics in Saudi Arabia, we employed the recently developed method of impulse indicator saturation (IIS) (Hendry et al. (2008); Johansen and Nielsen (2009); Hendry and Santos (2010)).

The choice of the IIS method is driven by various motivations. First, the approach has good statistical power to detect such shifts, both in static and dynamic models (Santos 2008). Additionally, the new break test allows for the possibility of using it in models with lagged dependent variables. Furthermore, the method does not need a trimming factor, making it more suitable for a small sample which is the case in our study as we have only 44 annual observations.

The IIS is designed to detect outliers and structural breaks, both in the mean and in the variance, in econometric models. It is based on saturating the model with indicator impulses, or dummy variables, for all observations.

In our case, we consider the following model that includes only constant and impulse indicators for every observation:

$$\text{CO}_2_t = \mu + \sum_{s=1}^T \delta_s I_{s,t} + \varepsilon_t, \quad \varepsilon_t \sim \text{iid}(0, \sigma^2), \quad T = 1, \dots, T \quad (8)$$

where  $I_{s,t} = 1$  for period  $s$  and 0 otherwise.

The principle of the method can be explained as follows: for a given econometric model, there are potentially  $T$  such dummy variables. However, the inclusion of all of them in a model is infeasible. The IIS proposes to include the impulse indicator dummies in the model as the separate blocks.

Suppose that we have two blocks, the sample is therefore divided on two equal-sized samples ( $T/2$ ). Firstly, the impulse indicator dummies are considered only for the first half of the sample, and statistically significant dummies for a specific significant level are kept. In addition, the impulse indicator dummies selected at the former step are eliminated, and then another part of the dummies is included in the model. Secondly, the same procedure is followed for the second half of the sample. Finally, the statistically significant impulse indicator dummies obtained from the two blocks are combined, and only jointly significant dummies are taken. For more details on the method and its applications, the reader may refer to Hendry et al. (2008) and Johansen and Nielsen (2009), Santos and Oliveira (2010), and Castle et al. (2015).

For our case, the impulse saturation break test investigates adding 44 indicators, as our sample size is 44 observations, to the model governing  $\text{CO}_2$  emissions (Eq. 8). We opt for sub-samples of  $T/2$ , so that we examine adding the first 22 impulse indicators corresponding each of the first 22 observations and

storing the statistically significant ones; then adding the remaining 22 indicators. In other words, in each of two steps, 22 indicators were added to the model given by Eq. 8.

The implementation of the procedure was done by the impulse indicator saturation (ISAT) function, which is available in the R [GETS Package](#).

We applied the indicator saturation break tests to identify potential break points in  $\text{CO}_2$  emissions, over the period 1971–2014, using the predefined model and at 1% significance level. Eventually, only significant coefficients retained in the regressions. The result of the IIS method is plotted in Fig. 2 and the regression results for the variable  $\text{CO}_2$  emissions are given in Table 4.

Figure 2 above shows that there is a single structural break date that corresponds to 2003 for the  $\text{CO}_2$  dynamics. It is also important to note that the obtained break point was chosen endogenously through the IIS break test. More importantly, it reflects a real economic change in Saudi Arabia and this seems to be reasonable. The decade 2003–2013 is a decade of prosperity in the country. As stated in a recent report<sup>12</sup> of McKinsey Global Institute on 2015, “the average household incomes rising by about 75 percent in total from 2003 to 2013. An oil price boom from 2003 to 2013 fueled rising prosperity in Saudi Arabia, which became the world’s 19th-largest economy. GDP doubled, household income rose by 75 percent, and 1.7 million jobs were created for Saudis.” We estimate that these mutations are responsible for the increasing trend in  $\text{CO}_2$  emissions.

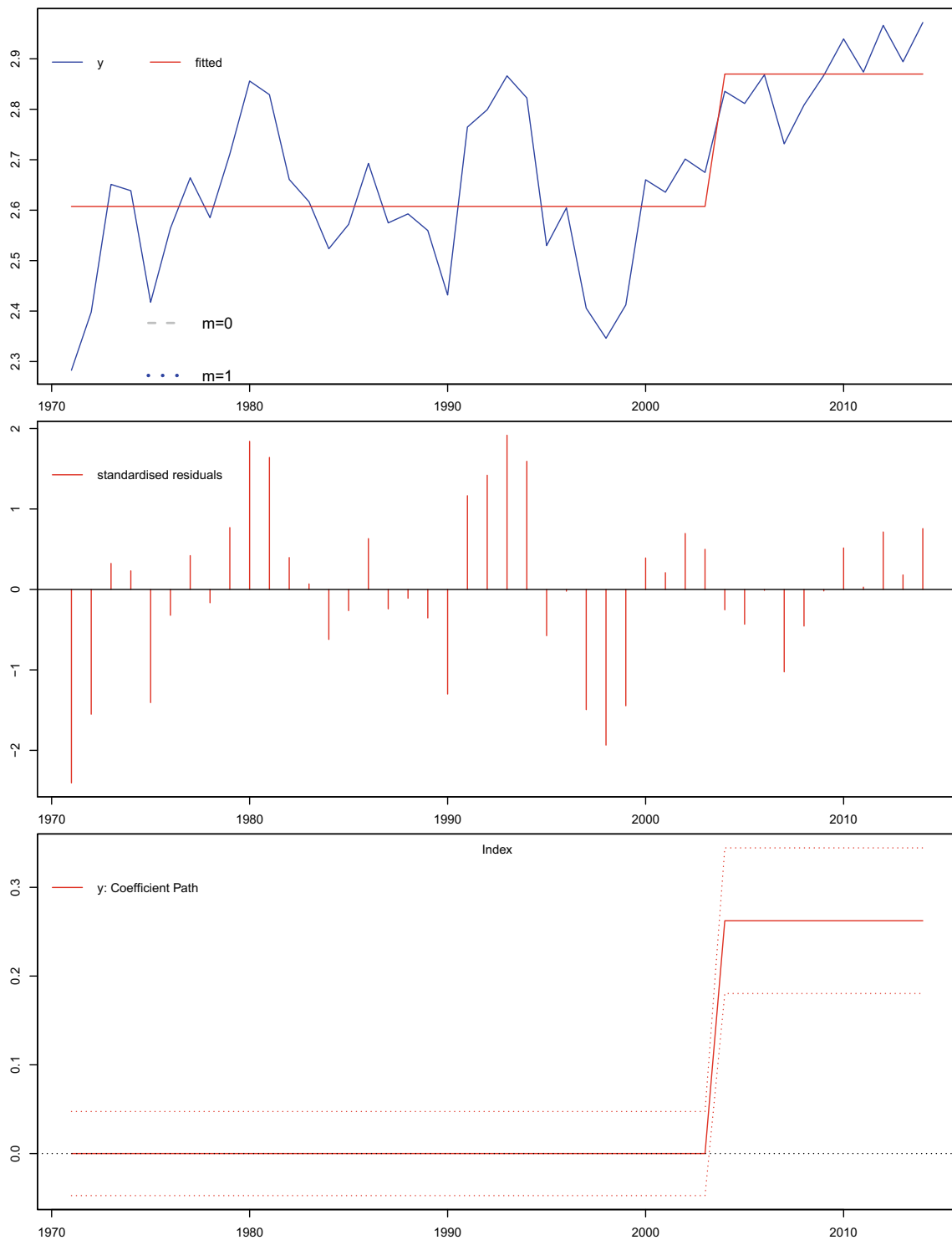
Based on the IIS method and taking account of the unit root test with break test, the endogenously determined break date, 2003, found in this study seems plausible, as it considers the events occurring in the Saudi economy. Our result is also compared to the result of Bai and Perron’s (BP) (2003) approach for multiple change detection. Both results are found similar in identifying the optimal break point. Tables and graphs for the BP (2003) are not reported here, to preserve space, and are available upon request from the author.

Therefore, an appropriate dummy variable considering the impact of this break, D03, will be included in the ARDL modeling approach.

### Results of cointegration analysis

The ARDL cointegration approach for estimating Eq. (3) requires two main stages. First, we begin by testing the existence of the long-run relationship among the variables, using the  $F$  test. Based on the bounds test (given in Table 5), the computed  $F$  statistic is 7.2, which clearly exceeds even the 1% critical

<sup>12</sup> McKinsey Global Institute report, Saudi Arabia beyond oil: The investment and productivity transformation.



**Fig. 2** Identified break with the indicator saturation method

value extracted from Narayan (2005) critical values at all rejection regions for the small-sample analysis. This result provides conclusive evidence of a long-run relationship between the carbon emissions per capita, energy use per capita, real GDP per capita, and urbanization at 1% significance level in Saudi Arabia.

Given the existence of a cointegration relationship among the variables, the ARDL cointegration method can be performed to estimate the coefficients of the model defined in Eq. (3) with maximum order of lag<sup>13</sup> fixed to 2. In the

<sup>13</sup> Following Narayan and Smyth (2004), the maximum number of lags in the ARDL was set equal to 2 given that annual data are used.

**Table 4** Regression results for CO<sub>2</sub> emissions

	Coefficient	Std. error	<i>t</i> value	<i>t</i> prob
Constant	2.607	0.023	110.92	0.000
I 2003	0.262	0.047	5.581	0.000

**Table 5** ARDL-bound test results

CO <sub>2,t</sub> = f(GDP <sub>t</sub> , EU <sub>t</sub> , URB <sub>t</sub> )		
<i>F</i> statistic	7.20	
Critical value bounds		
Significance	Lower bounds I0	Lower bounds I1
10%	2.893	3.983
5%	3.535	4.733
1%	4.983	6.423

Critical values are extracted from Narayan (2005) (Table case III: unrestricted intercept and no trend; pg. 1988)

*I0*, lower critical bound; *I1*, upper critical bound

literature, the Akaike Information Criterion (AIC) and the Schwartz Information Criterion (SIC) are the most used criteria for model selection. For our purpose, we opt for the SIC criteria since it tends to define a more parsimonious specification.

- First, our analysis focuses on testing the existence of the EKC hypothesis for the case of Saudi Arabia. As explained above, we follow the Narayan and Narayan's

(2010) approach in order to examine the presence of the EKC. Therefore, the short- and the long-run elasticities of GDP variable will be compared. The results for the short and the long run of the model, presented in Table 6, reveal that the long-run income elasticity is smaller than that of the short run. This finding signifies that the increase in income will be accompanied by a decrease in CO<sub>2</sub> emissions. In fact, in the long run (short run), a 1% increase in income rises carbon dioxide emissions by around 0.42% (0.88%). In other words, the economic growth still harmfully affects the environment, through CO<sub>2</sub> emissions, in both short and long run. Further, this outcome demonstrates that an inverted U-shaped relationship between economic growth and CO<sub>2</sub> emission does not exist as economic growth has a positive effect on CO<sub>2</sub> emission in both the short and long run in Saudi Arabia. It follows from this result the non-validity of the EKC hypothesis since the economic development of the country has not yet attained the level where pollution can be affected by the rise in economic growth. The obtained results are compatible with those of several studies that failed to validate the EKC hypothesis. For example, Samargandi (2017) and Taher and Hajjar (2014) showed no evidence of the EKC hypothesis or that the evidence of EKC hypothesis in Saudi Arabia is, at best, weak in the case of Saudi Arabia. The non-validity of the EKC hypothesis is also documented for several other countries around the world. For instance, Pao et al. (2011) examined CO<sub>2</sub> emissions, economic growth, and energy consumption relation for the period of 1990–2007 in Russia. The authors did not find the evidence of EKC for Russia and suggested energy conservation to overcome environmental pollution.

**Table 6** Estimated long- and short-run coefficients from error correction model

Variables	Coefficient	Std. error	<i>t</i> statistic	Prob
Estimated long-run coefficients				
LGDP	0.416	0.148	2.808	0.008
LEU	0.562	0.120	4.679	0.000
URB	−0.024	0.008	−2.993	0.005
D03	0.194	0.058	3.328	0.002
C	−5.287	2.133	−2.478	0.019
Estimated short-run coefficients				
ΔLCO <sub>2</sub> (−1)	0.254	0.128	1.984	0.056
ΔLGDP	0.883	0.207	4.264	0.000
ΔLEU	0.633	0.162	3.892	0.000
ΔLEU(−1)	−0.460	0.174	−2.637	0.013
ΔURB	−0.178	0.077	−2.321	0.027
ΔURB(−1)	0.206	0.070	2.933	0.006
ΔD03	0.1483	0.052	2.839	0.008
ECM(−1)	−0.760	0.153	−4.943	0.000

\*\*Significance level at 5%

**Table 7** Diagnostic tests of the ARDL model

Statistics tests	
Serial correlation	2.59 (0.09)
Functional form	0.79 (0.38)
Normality	3.76 (0.15)
Heteroscedasticity	0.77 (0.66)

The *p* value for diagnostic test is given in parentheses

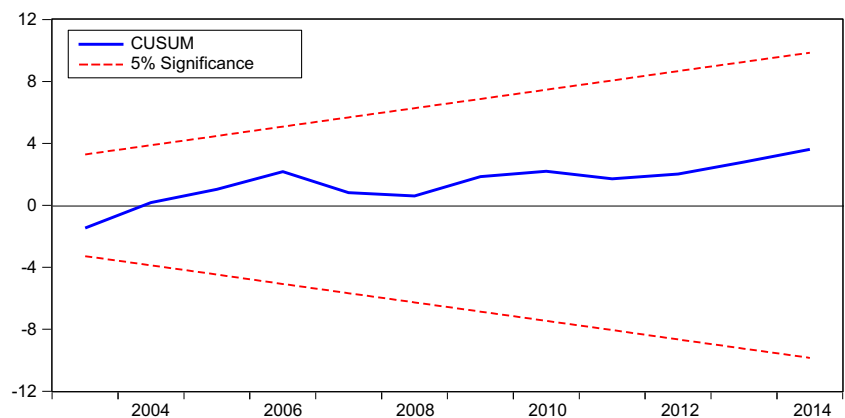
Similarly, Al-Mulali et al. (2015b) reported the non-validity of EKC hypothesis in Vietnam during the period 1981–2011, because they found a positive relationship in both the short and long run between GDP and pollution. Similarly, Lacheheb et al. (2015) failed to accept of EKC assumption in Algeria over the period 1971–2009. Also, Begum et al. (2015) found that the volume of production and CO<sub>2</sub> emissions in Malaysia follow a U-shaped relation, which demonstrates the non-validity of the EKC hypothesis. Moreover, Farhani and Ozturk (2015) showed the absence of EKC for Tunisia. However, our findings are divergent from those of Halicioglu (2009) for Turkey, Kohler (2013) for South Africa, Shahbaz et al. (2014a) for Tunisia, Shahbaz et al. (2014b) for United Arab Emirates, and Apergis and Ozturk (2015) and Amri (2017) for Algeria, for example.

- Second, we focus on energy use effect on CO<sub>2</sub> emissions. An increase of 1% in energy consumption will increase CO<sub>2</sub> emissions by 0.56% (0.63%) in the long run (short run). This signifies that more fossil fuel energy consumption will result in a more CO<sub>2</sub> emissions and therefore the environment will be more degraded. This result shows that environmental quality in Saudi Arabia is strongly linked the energy consumption. This finding is not surprising because Saudi Arabia is entirely dependent on fossil fuel consumption. Further, the country has experienced a fast transition to energy-intensive lifestyles and a rapid

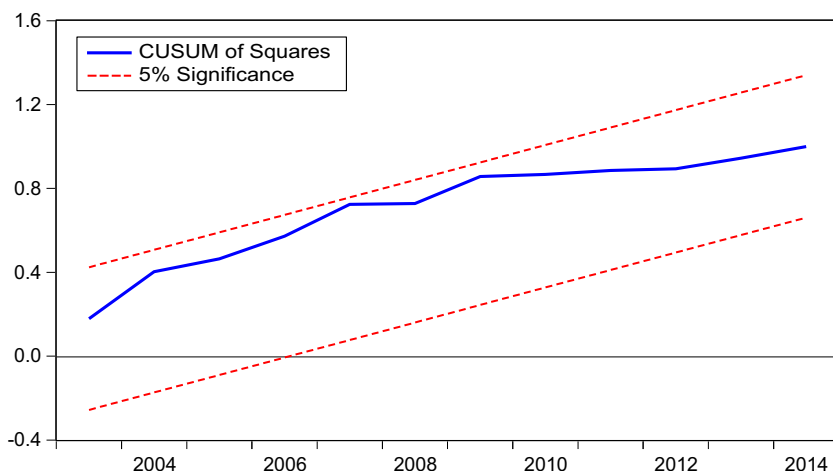
development of energy-intensive industries, such as petrochemicals and cement. These challenges are also catalyzed by the highly subsidized energy prices (Saudi Arabia Energy Efficiency Report 2012). Our results are supported, for example, by the findings of Hossain (2012) and Amri (2017), who reported that energy consumption leads to an increase in CO<sub>2</sub> emissions in Japan and in Algeria, respectively.

- Third, the results highlight that urbanization has a negative and statistically significant effect on CO<sub>2</sub> emissions in Saudi Arabia, so that, a 1% increase in urbanization reduces carbon emissions in Saudi Arabia by 0.024% in the long run against 0.178% in the short run. One possible explanation of this fact is that the potential benefits of urbanization exceed the disadvantages. As noted by Li and Yao (2009), Duh et al. (2008), and Schwartz and Kahn (2008), eventually, the population growth will develop throughout the landscape, resulting in an increase awareness of environmental impacts. With urbanization and population growth, stricter environmental standards and regulations are often part of energy and environmental policy. Additionally, urbanization is generally accompanied with the amelioration of public services such as roads or infrastructure that could contribute to the reduction of CO<sub>2</sub> emissions. Our finding is in accordance with several recent studies such as Sharma (2011) who applied a dynamic panel model, across 69 countries, and reported that urbanization has a negative impact on CO<sub>2</sub> emissions in high-income, middle-income, and low-income panels. Similarly, Saidi and Mbarek (2017) and Ali et al. (2017) found that urbanization could result in the reduction of carbon emissions for 19 emerging countries and for Singapore, respectively. However, our finding does not support the results found in some papers such as Al-Mulali et al. (2015a), Zhang and Lin (2012), Farhani and Ozturk (2015), and Ali et al. (2016).
- Fourth, the results indicate that the coefficient of estimated ECM (− 1), which measures the speed of adjustment to equilibrium, is statistically significant at 1% and in an expected

**Fig. 3** Plot of cumulative sum



**Fig. 4** Plot of cumulative sum square



sign. This result further confirms the existence of long-run relationship among variables under consideration. The estimated coefficient of  $-0.76$  suggests a fast adjustment process to long-run equilibrium of about 76% annually.

- Fifth, the dummy variable D03 corresponding to the endogenously determined structural break found in 2003, has significant and positive effect on CO<sub>2</sub> emissions, for both long run and short run. This result reflects the impact of economic mutation in Saudi Arabia, which is particularly related to the shape increase in oil prices since 2003.
- Finally, to check the appropriateness of the ARDL model of the estimated model, the ARDL diagnostic tests are performed and reported in Table 7. The results show that our model passes successfully the tests of serial correlation, functional form, normality, and heteroscedasticity. Additionally, we plot the CUSUM and the CUSUM of squares of residuals (Figs. 3 and 4, respectively) in order to verify the stability of the model. These figures justify the stability of the estimated model as the plots of both of them are within the boundaries of the 5% confidence interval.

## Conclusion and policy implications

In this paper, we have examined the relationships between economic growth, carbon emissions, energy use, and urbanization in Saudi Arabia over the period 1971–2014, using the ARDL approach to cointegration. The paper has also applied the recently impulse indicator saturation tests for break points detection, before setting the final form of the ARDL model. From the outcomes of our empirical investigation, various conclusions and policy implications can be drawn for Saudi Arabia:

- First, the results reveal the existence of a long-run cointegrating relationship among CO<sub>2</sub> emissions, economic

growth, energy use, and urbanization in Saudi Arabia in the presence of structural breaks, over the period 1971–2014.

- Second, the findings point to the non-validity of the EKC hypothesis for Saudi Arabia as the economic growth has a positive and significant impact on CO<sub>2</sub> emissions in both short and long run. The country has decreased its CO<sub>2</sub> emissions over time as income increases. However, it does not reach the level where pollution can be mitigated by the increase in GDP. Consequently, policy-makers should focus simultaneously on the economic growth and environmental issue in the context of Saudi Arabia in order to reduce the pollution in the country. In this context, the EKC analysis suggests that there is a need for Saudi Arabia to adopt effective environmental policies to mitigate the effect of pollution regardless of its economic growth.
- Third, as fossil fuel is harmful for environment, the fast growing of domestic demand of oil could intensify the deterioration of environmental quality through carbon dioxide emissions. Consequently, Saudi Arabia should adopt some policy actions such as enhancing efficiency energy and the rationalization of energy consumption. These strategies should concentrate on sectors that heavily rely on fossil fuel such as buildings, transportation, and industry, which represent more than 90% of the total energy consumption in the country. The policies may be achieved, for example, through the construction of public transport network within cities, the use of fuel-saving cars, improving the methods of isolation at buildings, and encouraging the use of efficient energy technology. With these actions, the country could reduce its fossil fuel consumption and therefore reduce CO<sub>2</sub> emissions. Renewable energy sources (e.g., solar, wind, geothermal, [waste-to-energy](#)) are also important options, in the medium and the long term, for Saudi Arabia for reducing its CO<sub>2</sub> emissions. In particular, the country has a high potential for renewable energy sources such as wind and solar, which are sufficient to make significant contribution to the country's energy supply (Faisal et al. 2012). However, any adopted policy should take account

Appendix

**Table 8** Chronological summary of the main studies related to Saudi Arabia

Author (s)	Country(-ies)	Relationship	Period	Methodology	Main results
Al-Friani (2006)	GCC countries	Energy consumption, economic growth	1971–2002	Panel cointegration and Granger causality	-Unidirectional causality from economic growth to energy consumption
Mehraa (2007)	11 selected oil-exporting countries	Per capita energy consumption and the per capita GDP	1971–2002	Panel cointegration and Granger causality	-Unidirectional strong causality from economic growth to energy consumption
Arouri et al.(2012)	12 MENA countries	Energy consumption, economic growth and CO <sub>2</sub> emissions	1981–2005	Panel cointegration + Granger causality	- Energy consumption has a positive impact on CO <sub>2</sub> emissions
Alkhatlan and Javid (2013)	Saudi Arabia	Economic growth, carbon emissions, and energy consumption	1980–2011	ARDL bounds tests + Granger causality	- Poor evidence in support of the EKC hypothesis -CO <sub>2</sub> emissions increase with the increase in per capita income - Income elasticity of CO <sub>2</sub> is negative for the gas consumption model. -Income elasticity of CO <sub>2</sub> is positive for the oil consumption model.
Alshetry and Belloumi (2014)	Saudi Arabia	Fossil fuel consumption and economic growth	1971–2012	Cointegration of Johansen and causality tests	-Unidirectional causality from economic growth to energy consumption in the long run and absence of causality in the short run
Banafea (2014)	Saudi Arabia	Economic growth and energy consumption	1971–2012	Gregory and Hansen (1996) cointegration procedure and ECM	-Causal relationship between real GDP and oil consumption in both the short and long run. - Short-run unidirectional causality running from real GDP to oil. - Long-run unidirectional causality running from oil consumption to real GDP. No evidence or weak EKC
Taher and Hajjar (2014)	Saudi Arabia	Real GDP, capital, labor, technological progress, and environmental pollution	1980–2010	A systems-wide approach	-Unidirectional causality in the long- and short-term between energy consumption and economic growth
Alshetry and Belloumi (2015)	Saudi Arabia	Energy consumption, carbon dioxide emissions, and economic growth	1971–2010	Johansen multivariate cointegration approach	- Used variables have short run and long run causal relationship with the ecological footprint.
Al-Mulali and Ozurk (2015).	MENA countries	Energy consumption, urbanization, trade openness, industrial output, political stability, and environmental degradation	1996–2008	Panel model + Pedroni cointegration test + Granger causality	- Bidirectional causality in both short and ong run between output and exports. -No evidence of causality in the short run between output and renewable energy consumption and between exports and renewable energy consumption
Hassine and Harrathi (2017)	GCC countries	Economic growth, renewable energy, financial development, and foreign trade	1980–2012	Panel cointegration approach + ECM	- Renewable energy use and exports are able to increase the economic growth. Non-validity of the EKC hypothesis -Volatility of electricity consumption negatively affects oil GDP levels and CO <sub>2</sub> emissions. -High and low volatility of oil GDP levels affect electricity consumption and CO <sub>2</sub> emissions positively.
Samargandi (2017)	Saudi Arabia	Sector value addition, technology, and CO <sub>2</sub> emissions	1970–2014	ARDL approach	-High volatility of non-oil GDP levels affects electricity consumption and CO <sub>2</sub> emissions positively.
Mezghani and Ben Hadda (2017)	Saudi Arabia	Real GDP, electricity consumption, and CO <sub>2</sub> emissions	1971–2010	Time-varying parameters vector autoregressive with stochastic volatility	Existence of EKC
Mahmood and Alkhatieb (2017)	Saudi Arabia	Trade and environment	1970–2016	EKC and ARDL cointegration test	

of the competitiveness of renewable energy relative to the fossil fuel sources (Taher and Hajjar 2014). For instance, the extremely high subsidies of energy prices in Saudi Arabia may not encourage energy consumers, especially in energy-intensive sectors, to make any important investments allowing their transition to the renewable energy sources.

- Urbanization decreases CO<sub>2</sub> emissions in Saudi Arabia. One possible explanation of this is that the potential benefits of urbanization exceed the disadvantages. With urbanization and population growth, stricter environmental standards and regulations are often part of energy and environmental policy.

The study is of great interest to policy-makers as it recommends that Saudi Arabia adopts measures to enhance energy efficiency and conservation in energy consumption. Furthermore, the country should explore new sources of green energy to achieve a sustainable economic growth. With the development of renewable energy sources, the country can preserve non-renewable fossil fuel resources, maintain its international energy leadership, and reduce its carbon dioxide emissions. Additionally, investments in clean energy sources create a wide array of other socioeconomic benefits. These include the creation of more jobs, a boost to income, and the promotion of environmental sustainability. Finally, urbanization was not found a barrier for growth in Saudi Arabia. However, the results we have presented show the need for more investigation and therefore can be extended in several ways.

In future research, one could include other potential determinants of CO<sub>2</sub> emissions like financial development, industrialization, trade openness, lifestyles, or oil price fluctuations, in the model specification, to explore the impacts of them on the environmental quality in Saudi Arabia. Another direction for future direction could be the use of nonlinear cointegrating autoregressive distributed lag (NARDL) model proposed by Shin et al. (2014) to investigate the existence of asymmetric cointegration between variables. Finally, one could extend our framework by improving the model specification used in the indicator saturation method, such as introducing an autoregressive component in the dynamic related to the dependent variable.

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