Energy Policy 62 (2013) 1525–1532

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

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

Khalid Alkhathlan *, Muhammad Javid

Economics Department, King Saud University, P.O. Box 2454, Riyadh 11451, Saudi Arabia

HIGHLIGHTS

- Carbon emissions increase with the increase in per capita income in Saudi Arabia.
- The income elasticity of CO_2 is negative for the gas consumption model.
- The income elasticity of CO_2 is positive for the oil consumption model.
- The results suggest that electricity is less polluting than oil and gas.

ARTICLE INFO

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

Keywords:
Oil
Gas
CO_2

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 CO_2 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 CO_2 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.

1. Introduction

In recent years, environmental pollution, greenhouse gases and climate change have been among the most important environmental concerns worldwide. The ever-increasing levels of carbon dioxide (CO_2) and other greenhouse gases in the atmosphere are considered to be among the world's greatest environmental threats. Among the greenhouse gases, CO_2 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 CO_2 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

* Corresponding author. Tel.: +966 555 227217; fax: +966 467 395517.
E-mail addresses: kathlan@ksu.edu.sa (K. Alkhathlan), mjavid@ksu.edu.sa (M. Javid).

0301-4215/$ - see front matter
http://dx.doi.org/10.1016/j.enpol.2013.07.068

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 CO_2 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 consumptions and carbon emission data. For the aggregate analysis, we use total energy consumption per capita and per capita CO_2 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 CO_2 emissions. Therefore, for the disaggregate analysis, we use oil, gas and electricity consumption along with their respective CO_2 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:

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

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 $\tau = exp(-\beta_1/2\beta_2)$

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), Ghali and El-Sakka (2004), Paul and Bhattacharya (2004), Lee (2006), Lee and Chang (2007), Kahsai 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), Akinlo and Long (2008), Jobert and Karanfil (2007), and Payne (2009). The conflicting results of these studies may be attributed to country-specific policies, the use of different energy consumption and income measures, the econometric methodology, omitted variable bias, model specifications and the varying time spans of the studies.

The third strand of the literature is a combined approach of these two methods that investigates the validity of both nexuses in the same framework. This approach investigates the dynamic relationships among economic growth, environmental pollution and energy consumption (see Ang (2007), Soytas et al. (2007), Soytas and Sari (2003), 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 Acaravci (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 CO_2 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 CO_2 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 CO_2 emissions, while financial development and trade openness have significant negative impact on CO_2 emissions. Alam et al. (2012) examined both short- term 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 multicollinearity 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:

$$co_t = \alpha_0 + \alpha_1 ec_t + \alpha_2 y_t + \varepsilon_t \quad (1)$$

where co_t is CO_2 emissions per capita, ec_t is total energy consumption per capita, y_t is real GDP per capita and ε_t is the error term. To examine the separate effect of these types of energy consumption on economic growth and CO_2 emissions and on the basis of Eq. (1), this study disaggregates total energy consumption into oil, gas and electricity consumption along with their respective CO_2 emissions as follows.

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

$$coo_t = \gamma_0 + \gamma_1 oc_t + \gamma_2 y_t + \varepsilon_{2t} \quad (2)$$

where coo_t is CO_2 emissions per capita from the consumption of oil, oc_t is per capita oil consumption and ε_{2t} is the error term.

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

$$cog_t = \delta_0 + \delta_1 gc_t + \delta_2 y_t + \varepsilon_{3t} \quad (3)$$

where cog_t is CO_2 emissions per capita from the consumption of gas, gc_t is the per capita gas consumption and ε_{3t} is the error term.

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

$$coel_t = \delta_0 + \delta_1 elc_t + \delta_2 y_t + \varepsilon_{4t} \quad (4)$$

where $coel_t$ is the CO_2 emissions per capita from the production of electricity and heat, elc_t is the per capita electricity consumption and ε_{4t} 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:

$$\Delta co_t = \alpha_0 + \sum_{i=1}^{p} \beta_{1i}\Delta co_{t-i} + \sum_{i=0}^{p} \beta_{2i}\Delta ec_{t-i} + \sum_{i=0}^{p} \beta_{3i}\Delta y_{t-i} + \beta_4 oc_{t-1} + \beta_5 ec_{t-1} + \beta_6 y_{t-1} + \beta_7 D + \varepsilon_t \tag{5}$$

where co_t is the carbon emissions per capita from aggregate energy, oil, gas and electricity consumption, and ec_t 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: $\beta_4=\beta_5=\beta_6=0$ against the alternative that H_1: $\beta_4 \neq \beta_5 \neq \beta_6 \neq 0$.

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-term and short-term models can be estimated as represented by Eqs. (6) and (7) below, respectively:

$$co_t = \alpha_2 + \sum_{i=1}^{p} \beta_{1i} co_{t-i} + \sum_{i=0}^{p} \beta_{2i} ec_{t-i} + \sum_{i=0}^{p} \beta_{3i} y_{t-i} + \varepsilon_{2t} \tag{6}$$

$$\Delta oc_t = \alpha_3 + \sum_{i=1}^{p} \beta_{1i}\Delta co_{t-i} + \sum_{i=0}^{p} \beta_{2i}\Delta ec_{t-i} + \sum_{i=0}^{p} \beta_{3i}\Delta y_{t-i} + \varphi ECT_{t-1} + \varepsilon_{3t} \tag{7}$$

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

$$ECT_{t-1} = co_t - \alpha_2 - \sum_{i=0}^{p} \beta_{2i} e_{t-i} - \sum_{i=0}^{p} \beta_{3i} y_{t-i}$$

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:

$$\Delta co_t = \alpha_3 + \sum_{i=1}^{p} \beta_{1i}\Delta co_{t-i} + \sum_{i=0}^{p} \gamma_{1i}\Delta ec_{t-i} + \sum_{i=0}^{p} \delta_{1i}\Delta y_{t-i} + \varphi_1 ECT_{t-1} + \varepsilon_{3t} \tag{8}$$

$$\Delta y_t = \alpha_3 + \sum_{i=0}^{p} \beta_{2i}\Delta co_{t-i} + \sum_{i=0}^{p} \gamma_{2i}\Delta ec_{t-i} + \sum_{i=1}^{p} \delta_{2i}\Delta y_{t-i} + \varphi_2 ECT_{t-1} + \varepsilon_{3t} \tag{9}$$

$$\Delta ec_t = \alpha_3 + \sum_{i=0}^{p} \beta_{3i}\Delta co_{t-i} + \sum_{i=1}^{p} \gamma_{3i}\Delta ec_{t-i} + \sum_{i=0}^{p} \delta_{3i}\Delta y_{t-i} + \varphi_3 ECT_{t-1} + \varepsilon_{3t} \tag{10}$$

where ECT_{t-1} is the lagged error correction term derived from the long-term cointegration relationship, and φ_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

Table 1
Results of the unit root test.

	ADF		Philips–Perron (PP)		Order of integration
	Level	First difference	Level	First difference	
y	−4.962*		−4.964*		I(0)
co_t	−2.584	−4.408*	−2.749	−4.368*	I(1)
coo_t	−0.548	−4.448*	−0.548	−4.398*	I(1)
$coel_t$	−1.776	−5.298*	−1.626	−5.409*	I(1)
cog_t	−2.272	−9.148*	−2.596	−12.473*	I(1)
ec_t	−0.122	−9.293*	−0.874	−12.058*	I(1)
oc_t	−0.399	−4.664*	−0.458	−7.721*	I(1)
$elec_t$	−1.816	−6.707*	−2.031	−6.637*	I(1)
gc_t	−2.396	−7.739*	−2.253	−7.491*	I(1)

Note: The regressions include an intercept. All of the variables are in natural logarithm, and the SBC has been used for the lag length.

* Indicates the rejection of the null hypothesis on the non-stationarity of the variable under consideration at a 1 percent level of significance.

Table 2
Results of the Zivot–Andrews structural break trended unit root test.

Variables	Level		1st Difference	
	t-Statistic	Time break	t-Statistic	Time break
y	−5.955(1)*	1991		
co_t	−0.859(0)	1985	−4.729(1)*	1985
coo_t	−0.522(0)	1985	−3.870(1)*	1996
$coel_t$	−0.466(1)	1984	−3.852(0)*	1988
cog_t	−1.241(1)	1985	−7.392(0)*	1985
ec_t	−0.768(1)	1993	−6.506(0)*	2005
oc_t	−2.003(1)	1990	−5.093(0)*	1992
$elec_t$	−1.376(2)	1990	−3.679(1)*	1984
gc_t	−1.311(0)	1986	−6.607(1)*	1985

Note: All variables are in natural logarithm. Lag order are given in parenthesis.

* Indicates the rejection of the null hypothesis of non-stationarity at a 1 percent level of significance.

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)–(C) involve the following equations:

$$\text{Model (A)}\quad y_t = \alpha_0 + \alpha_1 DU_t + \beta t + \rho y_{t-1} + \sum_{i=1}^{p} \varphi_i \Delta y_{t-i} + e_t$$

$$\text{Model (B)}\quad y_t = \alpha_0 + \gamma DT_t + \beta t + \rho y_{t-1} + \sum_{i=1}^{p} \varphi_i \Delta y_{t-i} + e_t$$

$$\text{Model }(C)\quad y_t = \alpha_0 + \alpha_1 DU_t + \gamma DT_t + \beta t + \rho y_{t-1} + \sum_{i=1}^{p} \varphi_i \Delta y_{t-i} + e_t$$

where DU_t is the intercept dummy indicates a one-time shift in the level; $DU_t=1$ if $(t>\text{TB})$ and zero otherwise; DT_t is the slope dummy represent a change in the slope of the trend function; $DT=t-\text{TB}$ if $t>\text{TB}$ 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 Criterion (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 monotonically 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

[1] Detail 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.

Estimated model	Total energy consumption	Petroleum consumption	Gas consumption	Electricity consumption
F-test for cointegration	5.67**	6.85**	6.12**	8.21*
Pesaran et al. (2001) critical values	1% level[a]	5% level[a]	10% level[a]	5% level[b]
Lower bounds	5.15	3.79	3.17	2.72
Upper bounds	6.36	4.85	4.14	3.83
Narayan (2005) critical values				
Lowe bounds	6.183	4.267	3.437	
Upper bounds	7.878	5.473	4.470	
Diagnostic tests				
R^2	0.934	0.859	0.986	0.997
Adjusted R^2	0.923	0.844	0.982	0.996
DW	1.89	1.75	1.68	2.13

[a] Unrestricted intercept and no trend.
[b] No intercept and no trend.
* Indicates the rejection of null hypothesis no cointegration at 1% significance level.
** Indicates the rejection of null hypothesis no cointegration at 5% significance level.

Table 4
Estimated coefficients.

Sector/variables	Total energy consumption	Petroleum consumption	Gas consumption	Electricity consumption
Panel A: Long-term elasticities				
y_t	0.45 (3.10)	0.56 (1.59)	−0.41 (−9.16)	0.24 (2.56)
ec_t	0.82 (7.37)	1.10 (2.94)	1.17 (13.03)	0.62 (40.33)
Constant	−5.93 (−4.26)	−7.61 (−1.81)		−5.57 (−6.14)
Panel B: Short-term elasticities				
Δy_t	0.20 (1.99)	0.13 (1.82)	−0.69 (−2.41)	0.14 (3.13)
Δy_{t-1}			−0.39 (−2.08)	
Δec_t	0.36 (5.05)	0.25 (3.12)	0.82 (8.66)	0.36 (5.57)
Constant	−2.62 (-2.62)	−1.76 (−2.33)		−3.25 (-6.03)
ECM_{t-1}	−0.44 (−3.90)	−0.23 (−2.41)	−0.59 (−6.58)	−0.58 (−5.70)
Panel C: Diagnostic tests				
$\chi^2_{SC}(1)$	0.09 [0.769]	1.09 [0.304]	4.53 [0.051]	2.42 [0.129]
$\chi^2_{N}(2)$	1.89 [0.387]	0.01 [0.994]	1.52 [0.468]	0.41 [0.813]
$\chi^2_{H}(1)$	0.40 [0.533]	0.17 [0.678]	0.32 [0.573]	2.69 [0.109]
$\chi^2_{FF}(1)$	0.05 [0.819]	2.28 [0.143]	0.13 [0.724]	0.56 [0.461]

Note: *t*-Values are given in parentheses, and p-values are given in brackets. $\chi^2_{SC}(1)$ is the Lagrange multiplier test of residual serial correlation; $\chi^2_{N}(2)$ is the Jarque–Bera test of normality based on a test of skewness and kurtosis of the residual; $\chi^2_{H}(1)$ is a heteroskedasticity test based on the regression of squared residuals on squared fitted values; and $\chi^2_{FF}(1)$ 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 CO_2 emissions, energy consumption and economic growth in Saudi Arabia.

4.1. These results can be summarized as follows

There is strong evidence that economic growth and energy consumption (aggregate, oil, gas and electricity) Granger-cause carbon emissions in Saudi Arabia in both the short and long term. This result indicates that any change in per capita income and energy consumption that disturbs the long-term equilibrium is corrected by a counter-balancing change in carbon emissions. Our findings show that there is strong evidence that energy consumption (aggregate, oil, gas and electricity) causes economic growth in the long term, but there is no causal relationship in the short term. However, in the oil model, there is unidirectional causality from oil consumption to per capita income in the short term. For the gas model, there is unidirectional causality from per capita income to gas consumption in the short term.

There is evidence of short-term bidirectional causality between CO_2 emissions and per capita income in Saudi Arabia for the aggregate model. However, we find unidirectional causality from per capita income to CO_2 emissions for the oil consumption model. Similarly, there is unidirectional causality from CO_2 emissions to per capita income for the gas consumption model. Between CO_2 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 CO_2 emissions equations. Similarly, CO_2 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, CO_2 and the error correction term are also

Table 5
Granger causality test results.

The variables below are Granger-caused by the variables on the right		Short-term χ^2 statistic			Long-term *t*-statistic	Joint short- and long-term effects χ^2 statistic		
		Δco	Δy	Δec	*ECT*	Δco & *ECT*	Δy & *ECT*	Δec & *ECT*
Total energy consumption	Δco		3.72 (0.053)	30.82 (0.000)	−4.19 (0.000)		10.95 (0.01)	24.64 (0.000)
	Δy	4.40 (0.034)		0.06 (0.813)	−2.32 (0.028)	7.46 (0.006)		7.74 (0.005)
	Δec	19.7 (0.000)	0.052 (0.819)		−4.95 (0.000)	23.37 (0.000)	6.34 (0.012)	
Petroleum consumption	Δco		3.29 (0.069)	9.73 (0.002)	−2.41 (0.023)		7.76 (0.005)	9.32 (0.002)
	Δy	0.65 (0.417)		2.76 (0.096)	−3.68 (0.001)	0.97 (0.324)		19.81 (0.000)
	Δec	9.46 (0.002)	0.17 (0.684)		−0.06 (0.949)	0.004 (0.951)	6.77 (0.009)	
Gas consumption	Δco		0.008 (0.927)	67.48 (0.000)	−6.42 (0.000)		3.38 (0.066)	95.86 (0.000)
	Δy	3.69 (0.055)		0.211 (0.645)	−1.85 (0.074)	5.01 (0.025)		4.82 (0.028)
	Δec	34.44 (0.000)	7.37 (0.007)		−6.48 (0.000)	39.49 (0.000)	9.63 (0.002)	
Electricity consumption	Δco		24.77 (0.000)	32.15 (0.000)	−5.70 (0.000)		58.40 (0.000)	32.48 (0.000)
	Δy	1.02 (0.312)		2.58 (0.108)	−4.22 (0.000)	0.002 (0.968)		15.24 (0.000)
	Δec	14.89 (0.000)	0.51 (0.476)		−3.98 (0.000)	15.30 (0.000)	51.39 (0.000)	

p-Values are in parentheses.

jointly significant. Thus, for the aggregate energy consumption model, all three variables (per capita carbon emissions, per capita energy consumption and per capita income) are interrelated in causal relationships in the long term. The results at a disaggregate level in the oil consumption model show that in the long term, there is unidirectional causality from per capita income and per capita oil consumption to carbon emissions. Between per capita oil consumption and per capita income, there is bidirectional causality in the same model. For the gas consumption model, all three variables are interrelated in causal relationships in the long term. For the electricity model, per capita income, electricity consumption and the error correction term are jointly significant in the CO_2 emissions equations. In the per capita electricity consumption equation, per capita income, CO_2 and the error correction term are also jointly significant.

Both the long-term and the joint short- and long-term causality results support the finding that the Saudi Arabian economy is highly dependent on energy consumption and that high energy consumption leads to high carbon emissions. This relationship may exist because an increase in economic growth causes an increase in the demand for energy and indirectly generates an increase in carbon 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 monotonically increasing relationship between carbon emissions and per capita income in Saudi Arabia. Therefore, the EKC hypothesis does not hold for these three models. 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. 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.

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 CO_2 emissions.

References

Akbostanci, E., Serp, T-A., Tunc, G.I., 2009. The relationship between income and environment in Turkey: is there an environmental Kuznets curve?. Energy Policy, 37; , pp. 861–867.

Akinlo, A.T., Long, T.V., 2008. Energy consumption and economic growth: evidence from 11 Sub-Saharan African countries. Energy Economics 30, 2391–2400.

Alam, M.J., Begum, I.A., Buysse, J., Huylenbroeck, G.V., 2012. Energy consumption, carbon emissions and economic growth nexus in Bangladesh: cointegration and dynamic causality analysis. Energy Policy 45, 217–225.

Ang, J., 2007. CO_2 emissions, energy consumption, and output in France. Energy Policy 35, 4772–4778.

Altinay, G, Karagol, E., 2005. Electricity consumption and economic growth: evidence for Turkey. Energy Economics 27, 849–856.

Asafu-Adjaye, J., 2000. The relationship between energy consumption, energy prices and economic growth: Time series evidence from Asian developing countries. Energy Economics 22, 615–625.

Asghar, Z., 2008. Energy-GDP relationship: a causal analysis for the five countries of South Asia. Applied Economics International Development 8, 167–180.

Boden, T.A., Marland, G., R.J., Andres, 2011. Global, regional, and national fossil-fuel CO_2 emissions. Carbon Dioxide Information Analysis Center. Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, TN, U.S.A., doi: 10.3334/CDIAC/00001_V2011.

Cheng, B.S., 1996. An investigation of co-integration and causality between energy consumption and economic growth. Journal of Energy and Development 21, 73–84.

Chontanawat, J., Hunt, L.C., Pierse, R., 2008. Does energy consumption cause economic growth? Evidence from a systematic study of over 100 countries. Journal of Policy Modeling 30, 209–220.

Dhungel, K.R., 2008. A causal relationship between energy consumption and economic growth in Nepal. Asia-Pacific Develpoment Journal 15, 137–150.

Dinda, S., 2004. Environmental Kuznets curve hypothesis: a survey. Ecological Economics 49, 431–455.

Esteve, V., Tamarit, C., 2012. Threshold cointegration and nonlinear adjustment between CO_2 and income: the environmental Kuznets curve in Spain, 1857–2007. Energy Economics 34 (6), 2148–2156, 10.1016/j.eneco.2012.03.001.

Fatai, K., Oxley, L., Scrimgeour F., 2002. Energy consumption and employment in New Zealand: searching for causality. Paper Presented at NZAE Conference, Wellington, 26–28 June 2002.

Ghosh, S., 2002. Electricity consumption and economic growth in India. Energy policy 30, 9–125.

Ghali, K.H., El-Sakka, M.I.T., 2004. Energy and output growth in Canada: a multivariate cointegration analysis. Energy Economics 26, 225–238.

Grossman, G., Krueger, A., 1991. Environmental impacts of a North American free trade agreement. National Bureau of Economics Research Working Paper. No. 3194, NBER, Cambridge.

Halicioglu, F., 2007. Residential electricity demand dynamic in Turkey. Energy Economics 29 (2), 199–210.

Hamit-Haggar, M., 2012. Greenhouse gas emissions, energy consumption and economic growth: a panel cointegration analysis from Canadian industrial sector perspective. Energy Economics 34, 358–364.

Halicioglu, Ferda, 2009. An econometric study of CO_2 emissions, energy consumption, income and foreign trade in Turkey. Energy Policy 37, 1156–1164.

Jobert, T., Karanfil, F., 2007. Sectoral energy consumption by source and economic growth in Turkey. Energy Policy 35, 5447–5456.

Kahsai, M.S., Nondo, C., Schaeffer, P.V., Gebremedhin, T.G., 2010. Does level of income matter in energy consumption and GDP nexus: evidence from Sub-Saharan African countries. Research Paper No. 2010-7. West Virginia University Regional Research Institute.

Kijima, M., Nishide, K., Ohyama, A., 2010. Economic models for the environmental Kuznets curve: a survey. Journal of Economic Dynamic and Control 34, 1187–1201.

Lee, C.C., 2005. Energy consumption and GDP in developing countries: a cointegrated panel analysis. Energy Economics 27, 415–427.

Lee, C.C., 2006. The causality relationship between energy consumption and GDP in G-11 countries revisited. Energy Policy 34, 1086–1093.

Lee, C.C., Chang, C.P., 2007. Energy consumption and GDP revisited: a panel analysis of developed and developing countries. Energy Economics 29, 1206–1223.

Lise, W., Van Montfort, K., 2007. Energy consumption and GDP in Turkey: is there a cointegration relationship? Energy Economics 29, 1166–1178.

Lise, W., 2006. Decomposition of CO_2 emissions over 1980–2003 in Turkey. Energy Policy 34, 1841–1852.

Masih, A.M.M., Masih, R., 1997. On temporal causal relationship between energy consumption, real income and prices; some new evidence from Asian energy dependent NICs based on a multivariate cointegration/vector error correction approach. Journal of Policy Modeling 19 (4), 417–440.

Mehrara, M., 2007. Energy consumption and economic growth: the case of oil exporting countries. Energy Policy 35 (5), 2939–2945.

Narayan, P.K., 2005. The saving and investment nexus for China: evidence from cointegration tests. Applied Economics 37, 1779–1790.

Nasir, M., Rehman, F., 2011. Environmental Kuznets curve for carbon emissions in Pakistan: an empirical investigation. Energy Policy 39, 1857–1864.

Narayan, P.K., Smyth, R., 2008. Energy consumption and real GDP in G7 countries: new evidence from panel cointegration with structural breaks. Energy Economics 30, 2331–2341.

Narayan, P.K., Narayan, S., 2010. Carbon dioxide emissions and economic growth: panel data evidence from developing countries. Energy Policy 38 (1), 661–666.

Narayan, P.K., Smyth, R., 2005. Electricity consumption, employment and real income in Australia: evidence from multivariate Granger causality tests. Energy Policy 33, 1109–1116.

Ozturk, Ilhan, Acaravci, Ali, 2010. CO_2 emissions, energy consumption and economic growth in Turkey. Renewable and Sustainable Energy Review 14, 3220–3225.

Ozturk, Ilhan, Acaravci, Ali, 2012. The long-run and causal analysis of energy, growth, openness and financial development on carbon emissions in Turkey. Energy Economics 36 (c), 262–267 10.1016/j.eneco.2012.08.025.

Oh, W., Lee, K., 2004. Causal relationship between energy consumption and GDP: the case of Korea 1970–1999. Energy Economics 26 (1), 51–59.

Perron, P., 1989. The great crash, the oil price shock, and the unit root hypothesis. Econometrica 57, 1361–1401.

Pesaran, M.H., Shin, Y., Smith, R.J., 2001. Bounds testing approaches to the analysis of level relationships. Journal of Applied Econometrics 16, 289–326.

Payne, J.E., 2009. On the dynamic of energy consumption and output in the US. Applied Energy 86 (4), 575–577.

Paul, S., Bhattacharya, R.N., 2004. Causality between energy consumption and economic growth in India: a note on conflicting results. Energy Economics 26 (6), 977–983.

Sari, R., Ewing, B.T., Soytas, U., 2008. The relationship between disaggregate energy consumption and industrial production in the United States: an ARDL approach. Energy Economics 30, 2302–2313.

Saudi Arabia's Energy Efficiency Report, 2011. ⟨http://www05.abb.com/global/scot/scot316.nsf/veritydisplay/f90e53733342b472c125786400519e97/$file/saudi%20arabia.pdf⟩.

Sen, A., 2003. On unit root tests when the alternative is a trend break stationary process. Journal of Business and Economic Statistics 21, 174–184.

Shahbaz, M., Lean, H.H., 2012a. The dynamics of electricity consumption and economic growth: a revisit study of their causality in Pakistan. Energy 36, 146–153.

Shahbaz, M., Lean, H.H., 2012b. Does financial development increase energy consumption? The role of industrialization and urbanization in Tunisia. Energy Policy 47 (7), 473–479.

Shahbaz, M., Lean, H.H., Shabbir, M.S., 2012. Environmental Kuznets curve hypothesis in Pakistan: Cointegration and Granger causality. Renewable and Sustainable Energy Reviews 16 (5), 2947–2953.

Shahbaz, M., Mutasscu, M., Azim, P., 2013a. Environmental Kuznets curve in Romania and the role of energy consumption. Renewable and Sustainable Energy Reviews 18, 165–173.

Shahbaz, M., Ozturk, I., Afza, A., Ali, A., 2013b. Revisiting the environmental Kuznets curve in a global economy. Renewable and Sustainable Energy Reviews 25, 494–502.

Shahbaz, M., Hye, Qma, Tiwari, A.K., Leitao, N.C., 2013c. Economic growth, energy consumption, financial development, international trade and CO_2 emissions in Indonesia. Renewable and Sustainable Energy Reviews 25, 109–121.

Soytas, U., Sari, R., Ewing, B.T., 2007. Energy consumption, income and carbon emissions in the United States. Ecological Economics 62, 482–489.

Soytas, U., Sari, R., 2003. Energy consumption and GDP: causality relationship in G7 countries and emerging markets. Energy Economics 25, 33–37.

Soytas, U., Sari, R., 2009. Energy consumption, economic growth, and carbon emissions: challenges faced by an EU candidate member. Ecological Economics 68, 1667–1675.

Stern, D.I., 2000. A multivariate cointegration analysis of the role of energy in the U. S. macroeconomy. Energy Economics 22, 267–283.

Stern, D.I., 2004. The rise and fall of the environmental Kuznets curve. World Development 32, 1419–1439.

Tiwari, A.K., Shahbaz, M., Hye, M.Q.A., 2013. The environmental Kuznets curve and the role of coal consumption in India: cointegration and causality analysis in an open economy. Renewable and Sustainable Energy Reviews 18 (3), 519–527.

Toda, H.Y., Philips, P.C.B., 1993. Vector autoregrassions and causality. Econometrica 61, 1367–1393.

U.S. Energy Information Administration, 2012. ⟨http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=2&pid=2&aid=3&cid=SA,&syid=2007&eyid=2011&unit=BKWH⟩.

World Bank, 2011. World development indicators. Online Database, World Bank.

Zhang, X.-P., Cheng, X.-M., 2009. Energy consumption, carbon emissions, and economic growth in China. Ecological Economics 68, 2706–2712.

Zivot, E., Andrews, D., 1992. Further evidence of great crash, the oil price shock and unit root hypothesis. Journal of Business and Economic Statistics 10, 251–270.