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# Investigating the Causal Relationship between Fossil Fuels Consumption and Economic Growth at Aggregate and Disaggregate Levels in Saudi Arabia

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**ABSTRACT:** This paper studies the causal relationships between fossil fuels consumption, $CO_2$ emissions and economic activity at aggregate and disaggregates levels in Saudi Arabia using the multivariate cointegration approach. The results show the existence of a long-run equilibrium relationship between fossil fuels consumption, carbon dioxide emissions and economic growth. Moreover, in the long-run the causality is unidirectional running from economic growth to energy consumption and natural gas consumption whereas there is absence of causality in the case of oil consumption. Our results indicate that energy conservation policies might be enforced without affecting economic growth. Policies aimed at reducing fossil fuel consumption and controlling for $CO_2$ emissions may not affect negatively Saudi's economic growth. Hence, policy reforms aimed at reducing fossil fuels (oil and natural gas) subsidies become an urgent necessity in the near future in order to eliminate fossil fuel wastes.

**Keywords:** Oil consumption; natural gas consumption; economic growth.
**JEL Classifications:** C32; Q43.

## 1. Introduction

Even though, the causality relationship between energy use and economic output is a well-studied topic, the direction of causality is still a debate between energy economists. The relationship between energy use and economic growth has been therefore the subject of increasing attention since the pioneering work of Kraft and Kraft (1978), which has provided evidence to support unidirectional causality running from income to energy consumption for the United States over the period of 1947-1974. Since that date, many studies have been undertaken for many countries utilizing diverse methodologies and time series over various time periods. However even for the same country, the findings are divergent depending on the methodologies, proxy variables and the data used. In general, the findings could be summarized into four different results. The first type of studies finds unidirectional causality running from economic growth to energy consumption. In these studies, the energy conservation hypothesis is validated (Kraft and Kraft, 1978; Cheng and Lai, 1997; Soytas and Sari, 2003; Fatai et al., 2004; Al-Iriani, 2006; Mehrara, 2007; Narayan and Smyth, 2008, Sari et al., 2008; Khalid, 2012; Damette and Seghir, 2013). In the second type of studies, there is evidence to support the growth hypothesis which states the existence of unidirectional causality running from energy consumption to economic growth (Stern, 1993; Oh and Lee, 2004; Lee, 2005; Narayan and Smyth, 2007; Lee and Chang, 2008; Sari et al., 2008; Apergis and Payne, 2009; Wolde-Rufael and Menyah, 2010). The third type of studies supports the feedback hypothesis which implies bidirectional causality between energy consumption and economic growth (Glasure and Lee, 1995, 1996 and 1998; Masih and Masih, 1997; Ghali and El-Sakka, 2004; Paul and Bhattacharya, 2004; Francis et al., 2007; Lee et al., 2008; Belloumi, 2009; Sadorsky, 2011; Abid and Sebri,2012; Shahiduzzaman and Alam, 2012; Ben Abdallah et al., 2013; Mohammadi and Parvaresh, 2014). Finally the fourth type of studies supports the absence of causality between energy consumption and economic growth known as neutrality hypothesis (Akarca and Long, 1980; Yu and Hwang (1984), Yu and Choi, 1985; Stern, 1993; Cheng, 1996; Payne, 2009; Ozturk and Acaravci, 2010; Hossein et al., 2012). Ozturk (2010) and Cherfi and Kourbali (2012) discussed in detail these studies.

Studying the causal relationships between energy consumption, economic growth and $CO_2$ emissions for Saudi Arabia is very interesting for checking for policy reforms aiming at reducing energy consumption and controlling for $CO_2$ emissions without harmful to economic growth. Fossil fuel consumption has been largely subsidized in Saudi Arabia. This has led to overuse and misallocation of oil and natural gas resources.

Energy consumption in Saudi Arabia had increased by about five times between 1980 and 2010 whereas population had increased by only 176% during the same period (WDI, 2012). For the same period, energy consumption per capita had increased by 122%. It attained about 7043 kg of oil equivalent in 2010. It is considered as one of the highest levels of energy consumption per capita in the world. Saudi Arabia has also one of the lowest prices. The diesel price is about $0.8 per gallon in Saudi Arabia in 2012. Moreover, price gas is less than $0.50 per gallon.[1] According to the International Monetary Fund (IMF) (2013), energy consumption in Saudi Arabia continues in its tendency if urgent reforms are not undertaken. Energy subsidies attained about 20% of Saudi Arabia's gross domestic product in 2011.

In order to achieve economic and social objectives, Saudi Arabia has largely subsidized fossil fuels. According to the International Energy Agency (IEA) (2010) estimates, the amount of subsidies going to oil products accounted for about $ 17 billion out of a total of $ 25 billion in Saudi Arabia. Saudi's fossil fuel subsidies consumption represented about 4.5% of worldwide subsidies in fossil fuel consumption in 2008. The worldwide amount of subsidization in oil consumption was estimated to $ 312 billion in 2008 whereas it was $ 204 billion for natural gas consumption. Coal consumption subsidies were estimated to about $ 41 billion. Moreover, worldwide subsidies in fossil fuel production are important. They were estimated to about $ 100 billion per year (Global Subsidies Initiative (GSI), 2009). The total amount of subsidies of fossil fuels represents about 1% of world GDP (World Bank, 2009). According to IEA analysis, "if these subsidies were phased out by 2020 it would result in a reduction in primary energy demand at the global level of 5.8% and a fall in energy-related carbon-dioxide emissions of 6.9%, compared with a baseline in which subsidy rates remain unchanged", IEA, OPEC, OECD, WORLD BANK joint report, 2010.

The energy subsidies estimates are variable depending on energy prices and the approach used for their estimation. Worldwide oil subsidies were about $ 110 billion in 2012, with about $ 55 billion for gasoline and $ 55 billion for diesel. The top ten countries are Saudi Arabia ($ 15 billion for gasoline and $ 9 billion for diesel), Iran ($ 8 billion for gasoline and $ 13 billion for diesel), Indonesia ($ 11 billion for gasoline and $ 7 billion for diesel), Venezuela ($ 10.5 billion for gasoline and $ 2.5 billion for diesel), Egypt ($ 3 billion for gasoline and $ 5.3 billion for diesel), Algeria ($ 1.5 billion for gasoline and $ 5 billion for diesel), Libya ($ 1 billion for gasoline and $ 2 billion for diesel), Malaysia ($ 1.5 billion for gasoline and $ 1 billion for diesel), Kuwait ($ 1.7 billion for gasoline and $ 0.8 billion for diesel), UAE ($ 1.5 billion for gasoline and $ 0.5 billion for diesel). They represent about 90% of total global subsidies. The majority of these countries are oil producers. Fuel subsidies have long been viewed in many oil-producing countries as a way to share the resource wealth with a nation's citizens (Davis, 2013).

According to Davis (2013), the total global deadweight loss from fuel subsidies in 2012 was $ 44 billion (with $ 20 billion from gasoline and $ 24 billion from diesel). Saudi Arabia takes the big part with $ 12 billion in deadweight loss. Venezuela takes the second place with $ 10 billion in deadweight loss. Iran takes the third place with $ 8 billion in deadweight loss. When expressed per capita the pattern of deadweight loss is similar. Saudi Arabia remains in the first rank, with $ 450 in annual deadweight loss per capita.

The annual fuel subsidy amount per capita was about $ 850 in Saudi Arabia in 2012. It was ranked number two behind Qatar with an amount of $ 900 in 2012. According to Parry et al. (2007), fuel subsidies are different from subsidies in most other markets because of the substantial external costs. They include carbon dioxide emissions, emissions of local pollutants, traffic

[1] We usually consider here the US $.

congestion, and accidents. According to IEA (2012) and IMF (2013), the global value of energy subsidies is almost $ 500 billion annually.

According to Burniaux et al. (2009), the removal of energy consumption subsidies can result in a reduction of greenhouse gas emissions by 2% in 2020 and 10% in 2050. It is clear that elimination of fossil-fuel subsidies would result in major benefits mainly to climate and can help reducing climate changes and variability impacts (GSI, 2010).

The remove of energy subsidies and the return of the equivalent value to selected consumers as lump-sum transfers would lead to avoid the distortions and inefficiencies created by energy subsidies. These measures need policy reforms from governments. Reforms aiming at removing fossil fuel subsidies have been undertaken in some countries such as Indonesia, Malaysia and India. They are successful case studies (e.g., UNEP 2008; von Moltke et al., 2003). For example, Indonesia increased petrol prices by 44% to cut its annual subsidy bill of $ 20 billion. Also, Malaysia increased energy prices by 15%. The examination of these case studies can help develop and understand the necessary reforms in some OPEC members where fossil fuels are extensively subsidized.

Saudi Arabia is subsidizing fossil fuel products (oil and natural gas products) and electricity so that consumers are paying low prices comparatively to market prices. The government is paying the difference as a measure of repartition of the wealth of fuels. The overuse of energy due to its low price will lead to serious problems in the future. This is why this overuse will cause a dilemma for the coming generations.

Saudi Arabia is spending a large part of oil revenues on education, healthcare, infrastructure, housing, transport and communication. Moreover, it is paying the bill of subsidies on energy products. Hence, this will cause a competition in expenditure that will cause a slowdown in the economic growth of the country. It is estimated by the Unites Nations (UN) that Saudi Arabia is paying about 70% of the actual bill of energy prices consumed locally. Energy subsidies represent about 10% of the country's GDP (68% of subsidies are allocated to fuel, 32% to electricity). These ratios will increase given the direct correlation between subsidies and consumption, which is linked to population growth, and urban and commercial development among citizens and foreigners.

It is well known that economic growth and productivity plans will be negatively impacted if subsidies on energy products are not allocated to the necessitated people. Policy makers should take some measures for correcting subsidies programs, such as direct cash subsidies to the necessitated beneficiaries but not to all members of society. Current expenditure (such as bonuses, social security programs, food subsidies, wages and others) can serve as a replacement for direct energy subsidies.

Our research question is then to test for the causal relationships between energy consumption, $CO_2$ emissions and economic growth at aggregate and disaggregate levels of fossil fuels consumption and $CO_2$ emissions for Saudi Arabia using the multivariate cointegration approach of Johansen (1991, 1995). We check which hypothesis is valid for the case of Saudi Arabia: the "conservation hypothesis", the "growth hypothesis", the "feedback hypothesis" or the "neutrality hypothesis". Each hypothesis has its policy implications concerning the management of energy use by the national policy makers or deciders. For example, the first and latter hypotheses imply that policies aimed at reducing energy consumption have no impact on economic growth. If one of these two hypotheses is valid, policy reforms on fossil fuel subsidization should be adopted without impact on economic growth. If the growth hypothesis or the feedback hypothesis is valid for the case of Saudi Arabia, the adoption of reforms aimed at removing out fossil fuel subsidies should be complemented by some measures (such as investment in renewable energies and energy efficiency) in order to not affect economic growth in the long run.

The remainder of this paper is organized as follows. In section 2, we present an overview of fossil fuel resources in Saudi Arabia. In section 3, we present data and methodology. Section 4 reports the empirical results and their discussion. The last section concludes by some policy implications.

## 2. Fossil Fuel Resources in Saudi Arabia

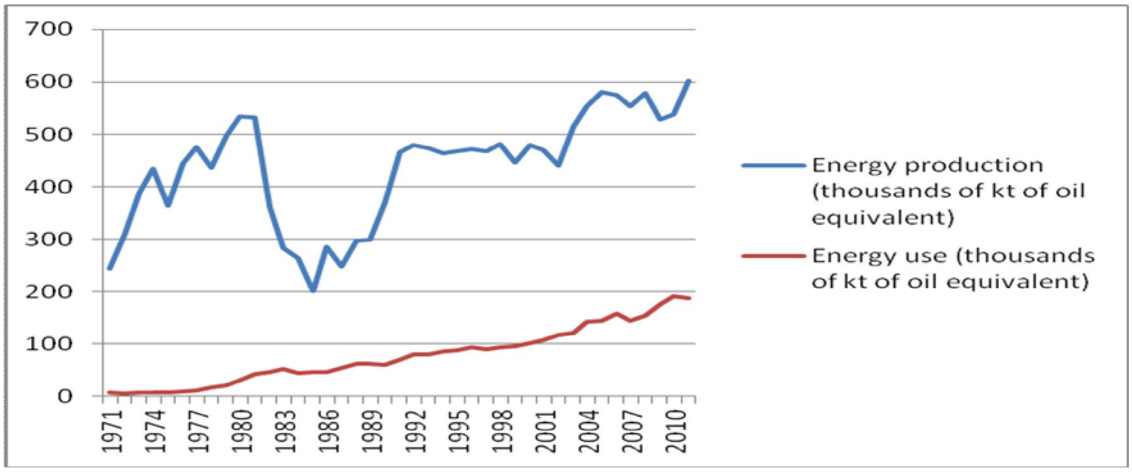
Saudi Arabia pumped approximately 11.532 million barrels per day of oil and 9.9 billion cubic feet per day of natural gas in 2012 (BP Statistical Review of World Energy June 2013). Saudi Arabia's global production reached 547 Million tons of oil and 92.5 million tons oil equivalent of natural gas in 2012 (BP Statistical Review of World Energy June 2013). Saudi Arabia is the major oil producer in the world accounting for 13.3 % of the global production in 2012 (BP Statistical Review of World

Energy June 2013). Saudi Arabia has one of the largest proven crude oil reserves in the world (about 36500 million tons in 2012) and its proved natural gas reserves are approximately 8.2 trillion cubic meters in 2012 (BP Statistical Review of World Energy June 2013). Its proven reserves of oil and natural gas represented respectively 15.9% and 4.4% of total world reserves in 2012. Saudi Arabia has the world's second largest reserves of oil and the world's sixth largest reserves of natural gas in 2012. The production of fossil fuels has played an important economic role in Saudi Arabia for decades. Saudi Arabia is the world's top oil exporter and producer. Saudi Arabia's economy is petroleum-based; Oil accounts for about 88% of the country's exports and nearly 75% government revenues in 2012 (WDI, 2013). Oil and natural gas rents represent about 58% of GDP in 2012. Saudi Arabia has per capita GDP of US$ 25,136 in 2012 (WDI, 2013). The economy of Saudi Arabia is still dependent on petroleum.

Saudi Arabia is the second largest energy consumer in the Middle East after Iran and the 12$^{th}$ largest energy consumer in the World in 2012 (SUSRIS, 2013). In 2012, its total primary energy consumption was about 222.2 Million tons oil equivalent of which 129.7 Million tons oil equivalent of oil and 92.5 Million tons oil equivalent of natural gas. Oil consumption represents about 58.35% of total primary energy consumption in 2012. The remainder was made up of natural gas (BP Statistical Review of World Energy June 2013). Due to energy subsidization, Saudi Arabia’s oil consumption doubled between 2000 and 2012. It attained 2935 thousand barrels per day (bbl/d) of oil in 2012 (U.S. Energy Information Administration, 2013).

Figure 1 depicts historical trends of energy consumption and energy production for Saudi Arabia. Saudi Arabia’s energy production grew by 146% between 1971 and 2011. For the same period, the Saudi Arabia’s energy consumption was multiplied by about 25 times. Historically, Saudi Arabia’s energy consumption and energy production are mainly composed of oil and natural gas. Figure 2 depicts historical trends of oil consumption and oil production for Saudi Arabia. Saudi Arabia’s oil production grew by 392% between 1965 and 2012. For the same period, the Saudi Arabia’s oil consumption grew by about 562%. It is also shown from figure 2 that the majority of oil produced is exported. Figure 3 depicts historical trends of natural gas production and consumption for Saudi Arabia. The two graphs of natural gas production and consumption are confounded. This implies that since 1970; all natural gas production is locally consumed. Saudi Arabia’s natural gas production and consumption were multiplied by 62 times over the period of 1970 to 2012.

**Figure 1.** Saudi Arabia’s energy consumption and energy production (in thousands kt oil equivalent) from 1971 to 2011




Electricity production is about 240.1 Terawatt-hours in 2010 (46.14% from natural gas and 53.86% from oil (WDI, 2013). Saudi Arabia is the fastest growing electricity consumer in the Middle East, particularly of transportation fuels. Electricity consumption in Saudi Arabia increased sharply during the 1971–2011 period due to rapid economic development. Electric power consumption per capita reached nearly 8161 kWh in 2011 representing about 25 times its 1971 level (WDI, 2013). The demand for power is increasing in Saudi Arabia. It is mainly driven by electricity subsidization and population growth (U.S. Energy Information Administration, 2013). Consequently, there is an urgent need to develop energy conservation policies for sustainable development. Saudi Arabia is planning to expand its generating capacity from 55 GW to 120 GW by 2020 (Energy Information Administration, 2013).

Fossil fuel consumption has led to the emissions of carbon dioxide. In Saudi Arabia, carbon dioxide emissions reached 615 million tons in 2012. Saudi Arabia was the $8^{th}$ top carbon dioxide emitter in the world in 2012. Between 1971 and 2010, $CO_2$ emissions per capita had increased by about 72% in Saudi Arabia (WDI, 2013).

Due to subsidization, natural gas prices in Saudi Arabia are the lowest in the Persian Gulf region. Saudi Arabia's gas production is generally not expensive, it is associated to an expensive high-sulfur gas production (U.S. Energy Information Administration, 2013).

**Figure 2.** Saudi Arabia's oil consumption and oil production (in million tons) from 1965 to 2012

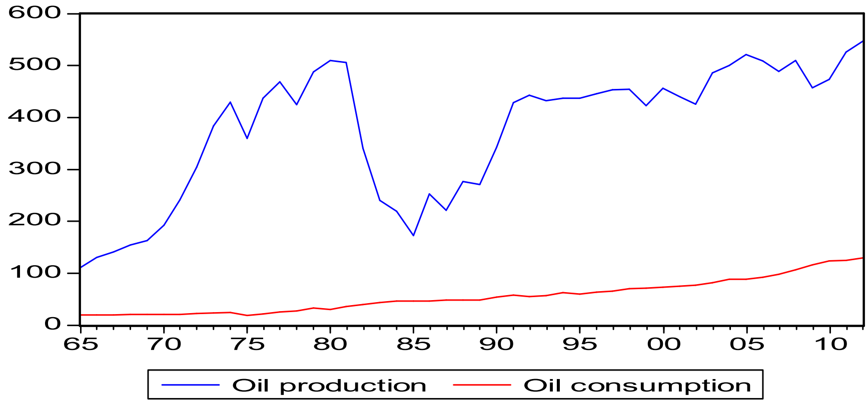
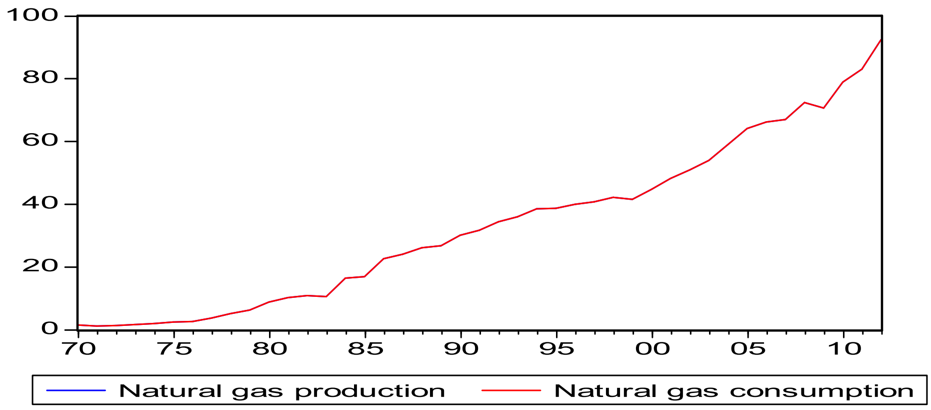



**Figure 3.** Saudi Arabia's natural gas consumption and natural gas production (in million tons oil equivalent) from 1970 to 2012




## 3. Data and Methodology

### *3.1. Data and Sources*

At the aggregate level, annual data for real GDP per capital (constant 2005 US $), total energy consumption per capita (kg oil equivalent) and $CO_2$ emissions per capita (metric tons) covering the period 1971–2012 are used for this study. For the disaggregate analyses, we use annual data on real GDP per capital (constant 2005 US $), oil consumption per capita (kg oil equivalent), natural gas consumption per capita (kg oil equivalent), $CO_2$ emissions per capita from consumption of oil (metric tons), and $CO_2$ emissions per capita from consumption of natural gas (metric tons). Data on oil consumption and natural gas consumption are obtained from BP Statistical Review of World Energy (June 2013). The rest of the data are obtained from the 2013 World Development Indicators of the World Bank. Description and descriptive statistics of the various variables are shown in table 1. The series are nominated as follows: LEUPC: natural logarithm of per capita energy consumption; LGDPPC: natural logarithm of real per capita GDP; LCO2PC: natural logarithm of per capita $CO_2$

emissions; LOCPC: natural logarithm of oil consumption per capita; LNGCPC: natural logarithm of natural gas consumption per capita; LCO2PCO: natural logarithm of $CO_2$ emissions per capita from consumption of oil and LCO2PCNG: natural logarithm of $CO_2$ emissions per capita from consumption of natural gas.

**Table 1.** Description and descriptive statistics

| Series | Description | Mean | Median | Std. Dev. | Max. | Min. | Ob |
|---|---|---|---|---|---|---|---|
| EUPC | Per capita energy consumption | 4017.88 | 4302.55 | 1739.08 | 7043.84 | 985.59 | 42 |
| GDPPC | Per capita GDP | 14838.45 | 12985.21 | 3466.81 | 22109.70 | 10423.19 | 42 |
| CO2PC | per capita CO2 emissions | 14.18 | 14.26 | 2.26 | 17.72 | 7.81 | 42 |
| OCPC | per capita oil consumption | 3470.70 | 3507.20 | 352.316 | 4531.94 | 2488.38 | 43 |
| CO2PCO | per capita CO2 emissions from oil | 7.60 | 8.66 | 2.895 | 11.193 | 1.01 | 43 |
| NGCPC | per capita natural gas consumption | 1583.86 | 1861.52 | 861.33 | 2894.30 | 200.34 | 41 |
| CO2PCNG | per capita CO2 emissions from natural gas | 3.33 | 4.07 | 2.24 | 6.84 | 0.0006 | 41 |

Figures 4, 5 and 6 show the evolution of the various series at the aggregate and disaggregate levels. It is shown that the different series have a common trend.

**Figure 4.** The evolution of natural logarithms of per capita energy consumption, real per capita GDP and per capita $CO_2$ emissions

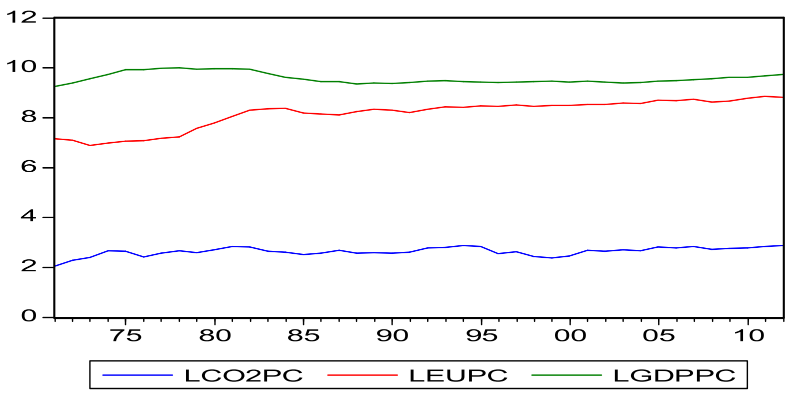



**Figure 5.** The evolution of natural logarithms of per capita oil consumption, real per capita GDP and per capita $CO_2$ emissions from consumption of oil

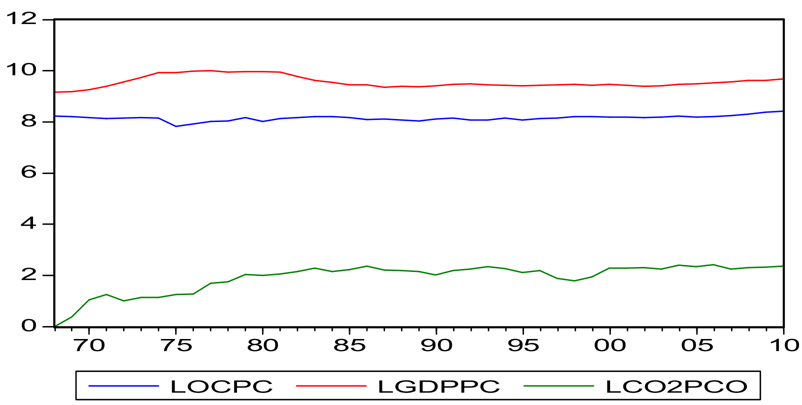
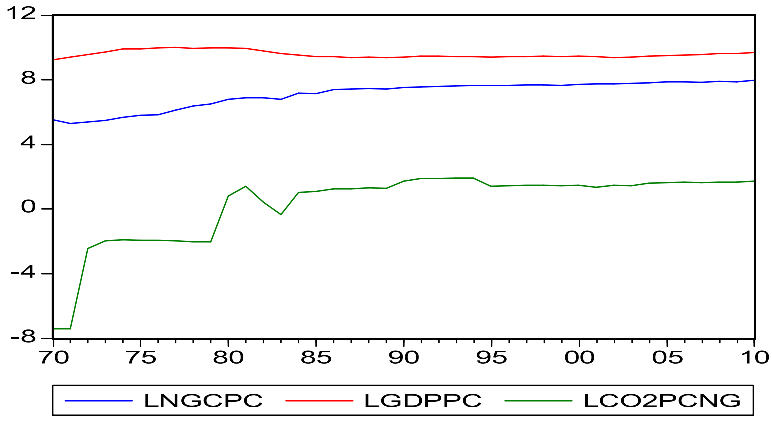


**Figure 6.** The evolution of natural logarithms of per capita natural gas consumption, real per capita GDP and per capita $CO_2$ emissions from consumption of natural gas




### *3.2. The multivariate cointegration technique of Johansen (1991, 1995)*

The multivariate cointegration technique of Johansen (1991, 1995) is used to examine the causal relationships between energy consumption, economic growth and $CO_2$ emissions at aggregate and disaggregate levels of fossil fuels consumption and $CO_2$ emissions for Saudi Arabia. At the aggregate level, we investigate the dynamic causal relationships between energy consumption per capita, $CO_2$ emissions per capita and real GDP per capita over the period 1971-2012. At the disaggregate level, we firstly analyze the causal relationships between oil consumption per capita, $CO_2$ emissions per capita from consumption of oil and real GDP per capita over the period of 1968 to 2010. Secondly, we investigate the causal relationships between natural gas consumption per capita, real GDP per capita and $CO_2$ emissions per capita from consumption of natural gas over the period of 1971 to 2010. The lengths of the periods are dictated by the availability of data on the various variables.

The Johansen approach is carried out in different steps. The Johansen technique is only valid when we are working with non-stationary series. Firstly, we have to apply the unit root tests in order to check for the stationary of the time series. In this study, we use both the augmented Dickey-Fuller (ADF) unit root tests (Dickey and Fuller, 1979) and Phillips-Perron (PP) tests (Phillips and Perron, 1988). When we find that the variables are integrated of the same order, we continue to test whether they are cointegrated or not using the cointegration tests developed by Johansen (1991, 1995). We choose the optimum lag length for the Johansen cointegration test based on the minimum of Schwarz Information Criteria (SIC) and Akaike Information Criteria (AIC) through the estimation of VAR models using the first differenced of variables as an auxiliary regression but not in terms of the levels. Also, when carrying carry out this test, we make an assumption regarding the trend underlying the data. In our models, we assume that the natural logarithms of the variables at their levels have no deterministic trends and the cointegrating equations have intercepts. Our choice is based on the analyses of figures 4, 5 and 6 and the results of unit root tests, which indicate that none of the variables have a deterministic trend. The Johanssen cointegration test may determine the number of cointegrating relations based on the trace and the maximum eigenvalue statistics. The cointegration rank, r, of the variables is determined using the maximum eigenvalue and trace test statistics. The trace test statistic is calculated under the null hypothesis $H_0$: $r_0 \leq r$ against the alternative hypothesis $H_1$: $r_0 > r$; where $r_0$ represents the number of cointegrating vectors. The maximum eigenvalue test statistic is calculated under the null hypothesis $H_0$: $r_0 = r$ against the alternative hypothesis $H_1$: $r_0 > r$ (Belloumi, 2009).

Finally, when cointegration is detected, vector error correction model (VECM) is estimated to deduce the direction of causality between the various variables for each model. The estimations of VECM, given by equations (1), (2) and (3), allow us to carry out the short-run and long-run Granger causality tests at aggregate and disaggregate levels:

$$\Delta y_t = \alpha_1 + \sum_{i=1}^{k} \beta_{1i} \Delta y_{t-i} + \sum_{i=1}^{k} \lambda_{1i} \Delta x_{t-i} + \sum_{i=1}^{k} \gamma_{1i} \Delta z_{t-i} + \eta_1 ECT_{t-1} + \varepsilon_{1t} \quad (1)$$

$$\Delta x_t = \alpha_2 + \sum_{i=1}^{k} \beta_{2i} \Delta x_{t-i} + \sum_{i=1}^{k} \lambda_{2i} \Delta y_{t-i} + \sum_{i=1}^{k} \gamma_{2i} \Delta z_{t-i} + \eta_2 ECT_{t\text{-}1} + \varepsilon_{2t} \quad (2)$$

$$\Delta z_t = \alpha_3 + \sum_{i=1}^{k} \beta_{3i} \Delta z_{t-i} + \sum_{i=1}^{k} \lambda_{3i} \Delta y_{t-i} + \sum_{i=1}^{k} \gamma_{3i} \Delta x_{t-i} + \eta_3 ECT_{t\text{-}1} + \varepsilon_{3t} \quad (3)$$

Where $y_t$ may be energy consumption per capita or oil consumption per capita or natural gas consumption per capita, $x_t$ is real GDP per capita and $z_t$ may be $CO_2$ emissions per capita or $CO_2$ emissions per capita from consumption of oil or $CO_2$ emissions per capita from consumption of natural gas; Δ is the first difference; $ECT_{t-1}$ are the error correction terms; $\varepsilon_{1t}$, $\varepsilon_{2t}$, and $\varepsilon_{3t}$ are the usual error terms.

We consider the two types of tests for Granger causality. The first one is the long-run causality that is determined by both the sign and significance of the error–correction terms. We say that the independent variables cause the dependent variable in the long term when the coefficient of the ECT is found to be negative and statistically significant. The second one is the short-run causality known also "weak Granger causality" which is determined by the joint significance of the coefficients of lagged terms of each independent variable using standard Wald tests.

## 4. Empirical Results and Discussion

We apply the ADF and PP tests for the nine time series in their levels and their first differences. The results of ADF and PP unit root tests are shown in table 2. They show that all the variables are non-stationary in levels at 5% critical value whereas their first differences are stationary at the same levels. Hence, we say that all the time series are integrated of order one. In this case, the variables can be cointegrated at aggregate and disaggregate levels.

**Table 2.** Results of ADF and PP unit root tests

| Model | Variables | ADF test | | | PP test | | |
|---|---|---|---|---|---|---|---|
| | | t-Stat. | | Critical values at 5% level | Adj. t-Stat. | | Critical values at 5% level |
| | | Levels | First differences | | Levels | First differences | |
| Energy consumption | LCO2PC | 0.829 | -6.441 | -1.95 | 0.873 | -6.760 | -1.95 |
| | LEUPC | 1.448 | -3.912 | -1.95 | 1.713 | -3.829 | -1.95 |
| | LGDPPC | 0.205 | -3.235 | -1.95 | 0.556 | -3.076 | -1.95 |
| Oil consumption | LOCPC | 0.352 | -7.654 | -1.95 | 0.486 | -7.946 | -1.95 |
| | LGDPPC | 0.474 | -2.939 | -1.95 | 0.569 | -2.888 | -1.95 |
| | LCO2PCO | 0.844 | -5.341 | -1.95 | 0.844 | -5.305 | -1.95 |
| Natural gas consumption | LNGCPC | 3.171 | -1.364 | -1.95 | 2.620 | -5.146 | -1.95 |
| | LGDPPC | 0.128 | -3.244 | -1.95 | 0.481 | -3.088 | -1.95 |
| | LCO2PCNG | -1.371 | -2.327 | -1.95 | -3.713 | -5.587 | -1.95 |

Note: All the results are given for the model without intercept and trend. Each ADF t-statistic is reported for shortest lag length which has been chosen based on minimum SIC. For the PP test, we choose the lag truncation for the non-parametric correction using an automated bandwidth estimator employing the Bartlett kernel.

In order to check if LEUPC, LGDPPC and LCO2PC, or LOCPC, LGDPPC and LCO2PCO, or LNGCPC, LGDPPC and LCO2PCNG are cointegrated, we apply the Johansen multivariate cointegration test. The optimum lag lengths used for Johansen cointegration test are shown in table 3.

**Table 3.** Selection of optimal lag lengths for the three models

| Number of lags | Energy consumption model | | Oil consumption model | | Natural gas consumption model | |
|---|---|---|---|---|---|---|
| | AIC | SIC | AIC | SIC | AIC | SIC |
| 5 | -4.134 | -2.023 | -3.315 | -1.226 | -2.969 | -0.836 |
| 4 | -4.743 | -3.045 | -3.753 | -2.072 | **-3.240** | -1.524 |
| 3 | -5.018 | -3.725 | -4.430 | -3.150 | -2.296 | -0.990 |
| 2 | -5.665 | -4.769 | -4.908 | -4.021 | -2.552 | **-1.647** |
| 1 | **-5.754** | **-5.247** | **-5.185** | **-4.683** | -1.614 | -1.102 |

They are chosen based on minimum of AIC and SIC through the unconstrained VAR estimation. Their values are equal respectively to 1 for energy consumption model, 1 for oil consumption model and 2 for natural gas model.

The results of Johansen cointegration test (Trace and Max-eigen statistics) for energy consumption model are given in Table 4. For the null hypothesis of no cointegration, the value of trace statistic is equal to 54.584 which is superior to the 5% and 1% critical values of 34.91 and 41.07, respectively. Hence the null hypothesis of absence of cointegration is rejected at both 5% and 1% levels of significance. The null hypothesis of the existence of one cointegrating relationship is also rejected at both 5% and 1% levels of significance given that the trace statistic of 25.121 is superior to the 5% and 1 % critical values of 19.96 and 24.60, respectively. Finally, the null hypothesis when the number of cointegrating vectors is equal to 2, is accepted at both 5% and 1% levels of significance given that the trace statistic of 8.626 is inferior to the 5% and 1 % critical values of 9.24 and 12.97, respectively. Hence, trace test indicates 2 cointegrating equations at both 5% and 1% levels. The same analysis could be done for the results of max-eigenvalue test. It indicates two cointegrating equations at the 5% significance level and one cointegrating equation at the 1% significance level. Hence, the results of trace and max-eigenvalue tests indicate the existence of at least one cointegrating relationship between energy consumption, carbon dioxide emissions and economic growth for Saudi Arabia.

The same analysis can be done for oil consumption and natural gas models. In the case of oil consumption model, the results of Johansen cointegration tests are shown in table 5 whereas for natural gas model they are given in table 6. In the case of oil consumption model, trace test indicates 2 cointegrating equations at both 5% and 1% levels whereas max-eigenvalue test indicates 2 cointegrating equations at the 5% level and no cointegration at the 1% level. In the case of natural gas consumption model, trace test indicates 2 cointegrating equations at the 5% level and 1 cointegration equation at the 1% level whereas max-eigenvalue test indicates 2 cointegrating equations at the 5% level and no cointegration at the 1% level.

**Table 4.** Results of Johansen cointegration tests

| Number of cointegrations | | Trace test | | | Max-eigenvalue test | | |
|---|---|---|---|---|---|---|---|
| | Eigenvalue | Trace statistic | 5% Critical value | 1% Critical value | Max-Eigen statistic | 5% Critical value | 1% Critical value |
| None | 0.530 | 54.584 | 34.91 | 41.07 | 29.462 | 22.00 | 26.81 |
| At most 1 | 0.345 | 25.121 | 19.96 | 24.60 | 16.495 | 15.67 | 20.20 |
| At most 2 | 0.198 | 8.626 | 9.24 | 12.97 | 8.626 | 9.24 | 12.97 |

**Table 5.** Results of Johansen cointegration tests for oil consumption model

| Number of cointegrations | | Trace test | | | Max-eigenvalue test | | |
|---|---|---|---|---|---|---|---|
| | Eigenvalue | Trace statistic | 5% Critical value | 1% Critical value | Max-Eigen statistic | 5% Critical value | 1% Critical value |
| None | 0.488 | 55.185 | 34.91 | 41.07 | 26.788 | 22.00 | 26.81 |
| At most 1 | 0.442 | 28.396 | 19.96 | 24.60 | 23.374 | 15.67 | 20.20 |
| At most 2 | 0.118 | 5.022 | 9.24 | 12.97 | 5.022 | 9.24 | 12.97 |

**Table 6.** Results of Johansen cointegration tests for natural gas consumption model

| Number of cointegrations | | Trace test | | | Max-eigenvalue test | | |
|---|---|---|---|---|---|---|---|
| | Eigenvalue | Trace statistic | 5% Critical value | 1% Critical value | Max-Eigen statistic | 5% Critical value | 1% Critical value |
| None | 0.496 | 46.66 | 34.91 | 41.07 | 25.39 | 22.00 | 26.81 |
| At most 1 | 0.372 | 21.26 | 19.96 | 24.60 | 17.23 | 15.67 | 20.20 |
| At most 2 | 0.103 | 4.03 | 9.24 | 12.97 | 4.03 | 9.24 | 12.97 |

However, even that cointegration implies the existence of Granger causality; it does not indicate the direction of the causality relationships. Hence, we estimate VEC models to run the short and long-run Granger causality tests at aggregate and disaggregate levels. These tests determine the direction of causal relationships between the various variables. Before applying the Granger causality tests, we check for the autocorrelation and homoscedasticity of the error terms of VEC models estimated by performing the autocorrelation LM test and the White VEC residual heteroskedasticity test. The results of these tests are shown in table 7. For a lag equal up to 12, the results of autocorrelation LM test show that we accept the null hypothesis of no serial correlation at a level of 5% for the three models. Also, the results of White VEC residual heteroskedasticity test show that we accept the null hypothesis of homoscedasticity at level of 5% with cross terms for the three models.

**Table 7.** Results of VECM residual tests

| Model | | Autocorrelation LM Test | VEC Residual Heteroskedasticity Test |
|---|---|---|---|
| Energy consumption model | Stat. | 5.065 | 91.960 |
| | Prob. | 0.828 | 0.258 |
| Oil consumption model | Stat. | 8.926 | 97.733 |
| | Prob. | 0.444 | 0.145 |
| Natural gas consumption model | Stat. | 7.362 | 227.419 |
| | Prob. | 0.599 | 0.194 |

We turn now to apply the short and long run Granger causality tests. The results of these tests are shown in table 8. At aggregate level, for energy consumption model, the coefficient of the ECT is found to be negative and statistically significant at the level of 10% in only the equation where energy consumption is the dependent variable. This result implies that there is a long-run causality running from $CO_2$ emissions and economic growth to energy consumption. In the short-run, all the probabilities are superior to 10%. This implies the absence of causality between all the variables. Hence, the energy conservation hypothesis is valid in the long term for the case of Saudi Arabia at aggregate level whereas we support the neutrality hypothesis in the short term that implies the absence of causality between energy consumption and economic growth.

At disaggregate level and in the case of oil consumption, all the coefficients of the error correction terms are either non negative or not statistically significant in the three equations. These results indicate the absence of long-run causality between oil consumption, economic growth and $CO_2$ emissions from the consumption of oil. In the short-run, there is unidirectional Granger causality running from oil consumption to economic growth and from economic growth to $CO_2$ emissions from oil consumption. Hence, in the long-run we support the neutrality hypothesis that implies the absence of causality between oil consumption and economic growth whereas the growth hypothesis is valid in the short term for the case of oil. Also in the short term, economic growth leads to more degradation of the environment.

At disaggregate level and in the case of natural gas consumption, the coefficients of the error correction terms are negative and statistically significant at the level of 5% in the equations where natural gas consumption and $CO_2$ emissions produced by the consumption of natural gas are dependent variables. These results imply the existence bidirectional causal relationship between natural gas consumption and $CO_2$ emissions produced by the consumption of natural gas, a unidirectional causality running from economic growth to natural gas consumption and a unidirectional causality running from economic growth to $CO_2$ emissions caused by the consumption of natural gas. In the short-run, there is a bidirectional causality between economic growth and natural gas consumption, a unidirectional Granger causality running from economic growth to $CO_2$ emissions from consumption of natural gas and a unidirectional Granger causality running from natural gas consumption to $CO_2$ emissions produced by the consumption of natural gas. Hence, in the long-run we support the conservation hypothesis for the natural gas whereas the feedback hypothesis is valid in the short term for the case of natural gas. Economic growth and the use of the natural gas lead to more $CO_2$ emissions from the consumption of natural gas in both the short and long run. This result is expected as natural gas production is exclusively locally consumed in Saudi Arabia.

Overall, our results support the neutrality of fossil fuels consumption at aggregate and disaggregate levels to economic growth in the long term in Saudi Arabia.

In Saudi Arabia, oil and natural gas are extensively subsidized that lead to low levels of their prices. As a result, these fossil fuels are overused and the growth rates of their consumption have been much faster than economic growth since the seventies. Our results imply that reducing fossil fuels consumption at aggregate and disaggregate levels through reforming fossil fuel price policies might not affect economic growth in the long term in Saudi Arabia.

**Table 8.** Results of Granger causality tests

| Model | Dependent variable | Short-run causality ( $\chi^2$ Wald statistics) | | | Long-run causality | |
|---|---|---|---|---|---|---|
| | | | | | $ECT_{t-1}$ | |
| Energy consumption | | $\Delta LEUPC$ | $\Delta LGDPPC$ | $\Delta LCO2PC$ | Coef. | t-stat. |
| | $\Delta LEUPC$ | - | 0.844 (0.35) | 1.229 (0.26) | -0.039 | -1.95 |
| | $\Delta LGDPPC$ | 0.033 (0.85) | - | 0.117 (0.73) | 0.020 | 1.85 |
| | $\Delta LCO2PC$ | 0.245 (0.62) | 0.730 (0.39) | - | 0.054 | 2.40 |
| Oil consumption | | $\Delta LOCPC$ | $\Delta LGDPPC$ | $\Delta LCO2PCO$ | Coef. | t-stat. |
| | $\Delta LOCPC$ | - | 1.475 (0.22) | 0.495 (0.48) | -0.009 | -0.22 |
| | $\Delta LGDPPC$ | 2.786 (0.09) | - | 0.861 (0.35) | 0.086 | 2.86 |
| | $\Delta LCO2PCO$ | 0.463 (0.49) | 4.896 (0.02) | - | 0.377 | 4.49 |
| Natural gas consumption | | $\Delta LNGCPC$ | $\Delta LGDPPC$ | $\Delta LCO2PCNG$ | Coef. | t-stat. |
| | $\Delta LNGCPC$ | - | 13.49 (0.001) | 0.251 (0.88) | -0.112 | -2.56 |
| | $\Delta LGDPPC$ | 5.64 (0.06) | - | 3.40 (0.18) | -0.002 | -0.56 |
| | $\Delta LCO2PCNG$ | 4.66 (0.09) | 9.39 (0.009) | - | -0.043 | -6.85 |

Values in parentheses are p-values.

The main objective of several studies in the field of energy economics is to answer the following question: Does energy consumption cause economic activity, or the reverse? In this study, our findings support the neo-classical theory which states that energy is neutral to economic growth. In general, our results are not very different from those obtained in the case of Saudi Arabia by Al-Iriani (2006), Mehrara (2007), Alkhathlan et al (2012), Khalid (2012) and Damette and Seghir (2013). Al-Iriani (2006) found a unidirectional causality running from economic growth to energy consumption in the both short and long runs for the six countries of Gulf Cooperation Council (GCC) including Saudi Arabia. Mehrara (2007) found the same results of Al-Iriani (2006) for 11 oil exporting countries over the period 1970-2002. Alkhathlan et al (2012) found that energy consumption and $CO_2$ emissions do not Granger cause economic output. Khalid (2012) found that there is a unidirectional causal relationship running from economic output to energy consumption in the long run and no causal relationship between energy consumption and economic output in the short-run. Hossein et al (2012) found that there is a short-run unidirectional causality running from economic growth to energy consumption while there are no causal relationships between energy consumption, economic growth and prices in the log-run for Saudi Arabia. The findings of Damette and Seghir (2013) are unidirectional causality from energy consumption to economic growth in the short-run and unidirectional causality running from economic growth to energy consumption in the long-run for 12 oil exporting countries including Saudi Arabia. Alkhathlan and Javid (2013) found that energy consumption leads to economic growth in Saudi Arabia in the long term at aggregate and disaggregate levels (oil, gas and electricity). By studying the causal relationship between energy consumption and economic growth in Arab countries, Shahateet (2014) found the absence of causality in the two directions for the case of Saudi Arabia.

In contrast to Al-Iriani (2006), Mehrara (2007), Khalid (2012), Alkhathlan et al (2012) and Damette and Seghir (2013), Narayan and Smyth (2009) found a long-run bidirectional causal relationship between electricity consumption and economic growth and the absence of causality in the short-run. Sadorsky (2011) and Mohammadi and Parvaresh (2014) found the same results as Narayan and Smyth (2009) with the exception of bidirectional causality also in the short-run.

By reviewing all these studies, we can conclude that our results are in line with the majority of previous findings for the case of Saudi Arabia.

**5. Conclusions**

The main objective of this study is to analyze the causal relationships between energy consumption, economic growth and $CO_2$ emissions at aggregate and disaggregate levels of fossil fuels consumption and $CO_2$ emissions for Saudi Arabia using the multivariate cointegration approach of Johansen (1991, 1995). Overall, our results are summarized as follows. For the causal relationship between fossil fuels consumption and economic growth, we find unidirectional causality running from economic growth to energy consumption in the long run and absence of causality in the short run at aggregate level. In the case of oil model, there is absence of causality between oil consumption and economic growth in the long run and a unidirectional causality running from oil consumption to economic growth in the short run. In the case of natural gas model, in the long run the causality is running from economic growth to natural gas consumption whereas in the short run the causality between economic growth and natural gas consumption is in the two directions. For the causal relationship between fossil fuels consumption and their $CO_2$ emissions, we find that the direction of causality is from $CO_2$ emissions to energy use in the long run and absence of causality in the short run. At aggregate level of oil model, there is absence of causality between oil consumption and $CO_2$ emissions from consumption of oil in both the short and long run. In the case of natural gas model, we find bidirectional causal relationship between natural gas consumption and $CO_2$ emissions produced by the consumption of natural gas in the long run whereas in the short run the causality is running from natural gas consumption to $CO_2$ emissions from consumption of natural gas. For the causal relationship between economic growth and $CO_2$ emissions, the results indicate the absence of causality between economic growth and $CO_2$ emissions in both the short and long run at aggregate level. However, at disaggregate level, in the long run there is absence of causality between economic growth and $CO_2$ emissions from the consumption of oil whereas in the short run economic growth Granger causes $CO_2$ emissions from the consumption of oil. In the case of natural gas model, economic growth causes $CO_2$ emissions produced by the consumption of natural gas in both the short and long run.

Our results approve the policies aimed at reducing fossil fuels consumption and $CO_2$ emissions without affecting the country's economic development and copying with the climate change policies. The main reason for the neutral impact of energy on economic growth is that the cost of energy is negligible in Saudi Arabia, so it is not likely to have a significant impact on economic growth (Belloumi, 2009).

Saudi Arabia should invest largely in energy conservation policies to reduce energy consumption and $CO_2$ emissions. On the basis of our results, we can conclude that energy conservation policies and controlling $CO_2$ emissions cannot have adverse effect on economic growth in Saudi Arabia in the long run.

International organizations are pressing Saudi Arabia for its heavy subsidization of fossil fuels (U.S. Energy Information Administration, 2013).. Increasing national energy prices to be in line with international market prices may play an effective role in reducing fossil fuels consumption and hence $CO_2$ emissions. Reforms of inefficient energy subsidies should be addressed in relation to the economic, social and environmental dimensions of sustainable development of the country. For Saudi Arabia, the first step in implementing reforms is to identify the inefficient subsidies that lead to wasteful consumption. Eliminating inefficient fossil fuels subsidies could have positive effects on the economy in the long run. Saudi Arabia should consider alternative policy measures to protect the poor such as cash and non-cash transfers because they could perform better than universal subsidies. Saudi Arabia has the necessary resources for setting up this system. Cash transfers have many advantages over universal subsidies and other types of transfers. Setting up the systems to implement a new program is indeed challenging but possible, as proved by the Indonesian case, but may require significant resources and a clear time frame. Funds collected by the government can be transferred directly to their recipients. The funds can play a big role in boosting economic growth, alleviating poverty and reducing greenhouse gas emissions.

Many previous studies have shown that fossil fuel subsidization is mainly in favor of rich households. For example in developing countries, only 15 to 20% of the fuel subsidies went to the bottom 40% of the population in terms of income distribution (IEA, OPEC, OECD, World Bank joint report, 2010).

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