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Measuring Energy Efficiency in GCC Countries Using Data Envelopment Analysis

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Energy efficiency is a key issue in determining the direction of global concern about preserving the environment. The Gulf Cooperation Council (GCC) is an emerging economic block of six countries with abundant oil reserves and high energy consumption. However, satisfying high levels of energy efficiency in GCC countries might hinder their fast growing economies. Therefore, it is important to measure energy efficiency of GCC countries in order to set the appropriate policies without adverse effects on their economic development strategies. This paper is the first attempt to measure energy efficiency in GCC countries using two models of Data Envelopment Analysis (DEA). As a complementary step, energy intensity for GCC countries and causality of the relationship between energy consumption and economic growth have been tested. The results indicate several policy implications with regard to energy conservation and efficient use of energy.

Keywords: GCC, Energy Efficiency, Energy Intensity

JEL Classification: C54, C81, Q48

I. Introduction

International concern over environmental issues such as global warming and climate change has put severe political and economic pressures on governments of both developed and less developed countries. Energy efficiency is one of the relevant targets to be met by international environmental standards. Therefore, improvement of energy efficiency is one of the most important objectives for any energy policy, especially for countries with high dependency on imported energy. It also exerts political pressures to deal with the climate change challenge (Al-Mansour, 2011).
The objective of improving energy efficiency is not only for environmental benefits, such as reducing CO_2 emissions, but also for attaining commercial, industrial competitiveness and energy security. However, the issue in measuring energy efficiency performance is to define the term "energy efficiency" (Patterson, 1996). Different definitions of energy efficiency would lead to different indicators being used to monitor changes in energy efficiency. In this paper we employ two models of DEA to measure and compare energy efficiency in GCC countries.

The problem of increasing energy efficiency in GCC countries by reducing energy consumption might slow down their economic growth where most GCC countries depend on fossil fuels, in particular oil. Thus, analyzing the relationship between the economic growth as presented by gross domestic product (GDP) and energy consumption is very important in setting energy policies.

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The relationship between GDP and energy consumption has been of interest to many researchers in energy economics (Hannesson, 2009). This interest has been stimulated by the unprecedented oil price increase of the early 1970s, which substantially increased the energy bill in oil-importing countries (Al-Iriani, 2006). Different studies have focused on different countries over different time periods to examine the relationships between energy and other macroeconomic variables (Haji and Said, 2011). To assess the effect of energy conservation policies on economic growth, the direction of the causality relationship between the GDP and energy consumption is usually tested (Sa'ad, 1010). In this paper, we will test the causality between these two variables for GCC countries to draw some policy implications.

As far as energy efficiency is concerned, this paper attempts to measure the energy efficiency in GCC countries using two different models of DEA and utilizes the results of the causality test between GDP and the energy consumption for each GCC country and for the GCC as a panel.

II. General Review of GCC Economies

GCC countries share several homogeneous aspects. They have the same language, culture, history and similar economic challenges which emphasize the need for economic integration and diversification. The GDP for the total GCC has increased from US$245 billion in 1980 to US$1,384 billion in 2011 as presented in Table 1.

Table 1: Major Development in GCC Countries, Economic Indicators (Billion US dollar)

Economic Indicator	*UAE*		*Bahrain*		*Saudi Arabia*		*Oman*		*Qatar*		*Kuwait*	
	2008	*2011*	*2008*	*2011*	*2008*	*2011*	*2008*	*2011*	*2008*	*2011*	*2008*	*2011*
Nominal GDP	254.4	366.2	21.9	25.8	472.3	592.5	60.3	67.9	100.4	173.5	148.2	158.0
Real GDP growth %	7.4	3.5	6.3	2.2	4.2	7.1	12.8	5.0	13.4	14.1	8.5	4.8
Interest rates on US Dollar (3 months)	2.2	0.3	2.4	0.3	2.2	0.3	2.9	0.7	2.2	0.3	2.9	0.7
Inflation rate	12.3	0.9	3.5	-0.4	9.9	5.0	11.8	4.0	15.1	1.9	10.6	4.7
Money supply*	29.1	1.6	20.8	5.3	17.6	13.3	23.1	12.2	21.9	27.5	15.9	8.5
Imports (FOB)	176.3	198.5	14.2	12.1	100.6	119.1	20.7	21.3	25.1	22.2	22.9	20.7
Exports (FOB)	239.2	295.5	17.3	19.9	313.4	364.6	37.7	47.1	54.9	111.4	78.0	95.1
Current account	22.3	52.3	2.3	3.3	132.3	158.5	5.5	9.6	14.2	51.4	64.8	62.7
Ratio of current account balance in GDP**	8.8	14.3	10.3	12.6	27.9	26.8	9.1	14.2	14.1	29.6	43.7	39.7
Government balance (% of GDP)**	136.0	7.4	7.5	-2.3	32.6	13.1	6.0	3.7	10.5	7.1	28.5	33.6
Population (million)	5.6	4.8	1.1	1.4	24.8	28.1	2.9	2.8	1.4	1.8	3.4	2.8

*M2 in Oman represents broad money supply, while M3 represents broad money supply in the remaining GCC countries.
**Ratio of surplus/deficit to GDP (at current prices)
Source: Saudi Arabian Monetary Agency, 2010 and 2012.

GCC countries excluding Bahrain are major producers and exporters of oil. They depend on oil revenue for their economic development as shown in Table 2.

Table 2: World Oil and Gas Reserves, Year End 2010

Region	*Oil Reserves*		*Gas Reserves*	
	Thousand Million bbls	*%*	*Trillion CM*	*%*
Americas	313.8	22.7	17.3	9.2
Europe and Eurasia	139.7	10.1	63.1	33.7
Middle East–of which:	752.5	54.4	75.8	40.5
(Gulf Region)	**749.2**	**54.2**	**74.8**	**40.0**
Africa	132.1	9.6	14.7	7.9
Asia Pacific	45.2	3.3	16.2	8.7
Total World	**1383.2**	**100**	**187.1**	**100**

Source: British Petroleum (BP) Statistical Review, 2011.

Recently, GCC countries have embarked on plans for developing their non-energy sectors such as manufacturing and developing renewable energy sources. Such a policy has been driven by the international search for energy alternatives to oil. A fast demographic change is another factor that puts pressure on GCC countries to diversify their economies from oil as the main source for economic development to meet employment aspirations.

The industrial development in the GCC is concentrating on industries, such as basic petrochemicals, fertilizers, and steel, as well as aluminum and non-durable consumer goods. Most of these industrial products are for export and are primarily energy intensive. However, to reach an effective diversification, GCC countries need to integrate economically and politically.

Table 2 shows that GCC countries collectively account for 54.2 percent of world proven oil reserves, and produce more than 21 percent of world crude oil production. As shown in Table 2, GCC countries have around 40 percent of world natural gas reserves and 9.1 percent of the world natural gas production. The GCC countries enjoy relatively cheap extraction costs of oil and gas, which puts them in an advantageous position relative to other oil and gas producers. The wealth generated by the GCC countries from oil and gas exports allows their economies to reach unprecedented development, with higher standards of living and modern physical infrastructure. However, subsidized domestic oil prices in GCC countries are contributing to high consumption of oil which will lead to high CO_2 emissions and reduce their energy efficiency. Therefore, GCC countries have to adopt an energy policy in line with the diversification and integration strategy which improves energy efficiency and economic growth.

III. Energy Efficiency

Energy efficiency generally refers to using less energy to produce maximum output. Patterson (1996) has introduced four types of indicators which can be used in measuring energy efficiency: thermodynamic, physical-thermodynamic, economic-thermodynamic and economic indicators. Each indicator differs in terms of the measurement unit of input and output. In this paper, we used the economic-thermodynamic indicators to compare the level of efficiency of each GCC country relative to one another. The most commonly used indicator to measure aggregate of a nation's energy efficiency is the energy GDP ratio, or usually called "energy intensity". Other methods exclude the extraneous factors, such as changes in energy input mix, energy for labor substitution, and changes in structure of economy, from the energy GDP ratio, in order to isolate the underlying technical energy efficiency.

Zhou and Ang (2008) use production framework to measure energy efficiency performance. By utilizing DEA, energy consumption is treated as one of the inputs within the production framework with labor and capital as other established economic inputs. Different energy sources are treated as different inputs so that changes in energy mix could be accounted for in evaluating energy efficiency. The undesirable output of energy input which is CO_2 emission is also included to measure the efficiency performance of 21 Organization for Economic Co-operation and Development (OECD) countries.

On the other hand, energy intensity as one of the indicators is used to measure energy efficiency. High energy intensities indicate a high cost of converting energy into GDP. Figures 1 and 2 show the trend of energy efficiency in GCC countries based on their energy intensity as one bloc and as individual countries, respectively.

Figure 1: Energy Intensity of GCC: As a Ratio of Energy/GDP

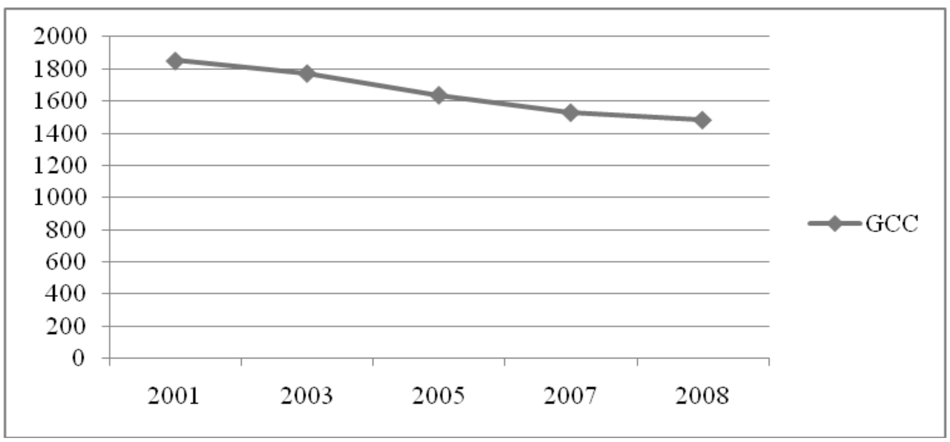

Figure 2: Energy Intensity of Individual GCC Countries: As a Ratio of Energy/GDP

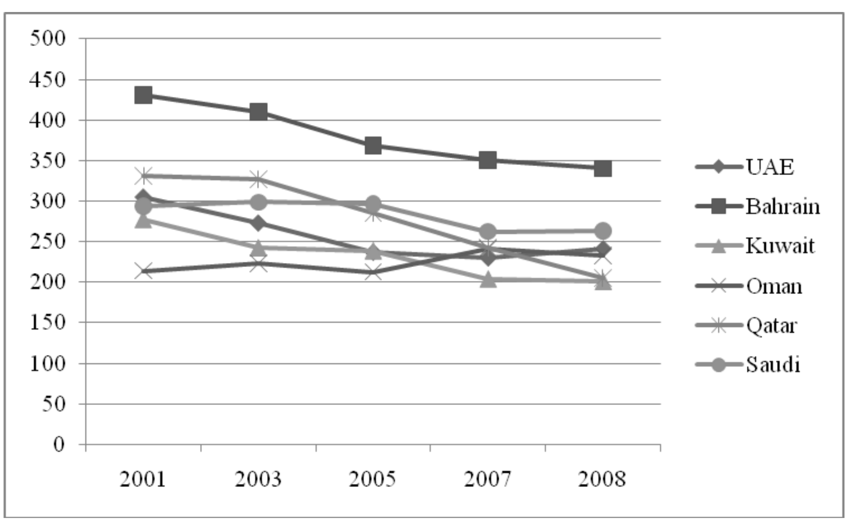

Figure 2 depicts Bahrain as the most inefficient GCC country in terms of energy intensity as a ratio of energy divided by GDP. Oman was the most efficient in 2001, 2003 and 2005, and it indicated some performance decreases in this efficiency level since its energy intensity was increased.

In 2007 and 2008, Kuwait became the most efficient GCC country with the lowest energy intensity. The UAE and Kuwait had shown good improvements in their energy efficiency in the last 8 years. Qatar had shown the highest level of improvement compared to other GCC countries and reached the most efficient country, Kuwait, in 2008. For Saudi Arabia, there was a moderate level of improvement in the energy efficiency over these time periods.

Many factors influence an economy's overall energy intensity. Such factors are the requirements for general standards of living and weather conditions. It is not typical for particularly cold or hot climates to require greater energy consumption in homes and workplaces for heating or cooling purposes, given the differences in standard of living.

Testing the causality between GDP and energy consumption is very essential for determining energy intensity. Empirical results in oil importing countries have been mixed (Chontanawat *et al.*, 2006 and Hertog and Luciani, 2009). This led to some confusion about the effects that energy conservation policies have on economic growth in both developed and developing countries. The disparity in results has most likely been a product of methodological and data differences.

Al-Iriani (2006) investigated the causality relationship between GDP and energy consumption in the GCC. He utilized the recently developed panel cointegration and causality techniques to test the direction of energy-GDP causality in the GCC. Results indicated a unidirectional causality running from GDP to energy consumption. Evidence shows no support for the hypothesis that energy consumption is the source of GDP growth in the GCC countries. Such results suggest that energy conservation policies have been adopted without much concern about their adverse effects on the economic growth of GCC countries.

Mehrara (2007) examined the causality issue between energy consumption and economic growth for three typical oil-exporting countries: Iran, Kuwait and Saudi Arabia. By using two different test methods, a unidirectional long-run causality from economic growth to energy consumption for Iran and Kuwait and a unidirectional strong causality from energy consumption to economic growth for Saudi Arabia were consistently shown.

Chontanawat *et al.* (2008) tested causality between energy to GDP for over 100 countries. He found that causality from energy to GDP more prevalent in the developed OECD countries, compared to the developing non-OECD countries. Its implication on policy is that reducing energy consumption aimed at reducing emissions is likely to have greater impact on the GDP of the developed rather than developing world.

IV. Measuring Energy Efficiency

In order to measure energy efficiency, we used two different models. The first model emphasizes more energy intensity, and the second model incorporates other economic factors in the measurement.

A. Model I

The objective is to maximize the DEA efficiency rating for each country as the relative efficiency of unit j using only energy consumption as input is given by

$$\frac{relative\ output\ value}{relative\ input\ value} = \frac{wyj}{vxj} \quad (1)$$

We define the variables as follows:

w = relative output weight applied to country's GDP
y = amount of output (GDP) from unit j
v = relative input weight applied to country's energy consumption
x = amount of input (energy consumption)
j = unit/ country being measured

Looking at the model, we can see that it is a non-linear function in the decision variables. However, since all quantities are relative to some value, we shall choose to make the denominator equal to 1. So vxj=1 will be a constraint in the model. Given this, the objective function is modified to $Max\ output = w\ yj$.

The second constraint is that all DEA efficiency ratings must not exceed 1 for all countries, $w\ yj \leq v\ xj$. All weights must be non-negative, shown as resulting in w,v ≥ 0.

Then Model I:

$$\begin{aligned} &\text{Max output} = wyj \quad (2)\\ &\text{Subject to } vxj = 1\\ &\quad wyl - vxl \leq 0 \qquad l=1,2,\ldots 9\\ &\quad w,v \geq 0 \end{aligned}$$

l = units (countries) included in the measurement

B. Model II

The objective is to maximize the DEA efficiency rating for each country. The relative efficiency of unit j using only economic factors as input is given as

$$The\ relative\ efficiency\ of\ unit\ j = \frac{wyj}{v1x1j + v2x2j + v3x3j}, \quad (3)$$

where

w = relative output weight applied to country's GDP
y = amount of output (GDP) from unit j
v1 = relative input weight applied to country's labor
x1j = amount of input 1 (labor) from unit j
v2 = relative input weight applied to country's energy consumption
x2j = amount of input 2 (energy consumption) from unit j
v3 = relative input weight applied to country's capital
x3j = amount of input 3 (capital) from unit j

Following the same steps we did for Model I in establishing the constraints, we came up with Equation (4) in Model II:

$$\text{Max output} = wyj \tag{4}$$

$$\textit{Subject to} \sum_{i}^{2} vt\,xtj = 1$$

$$wyl - \sum_{i}^{3} vi\,xil \leq 0 \qquad i = 1,2, \quad .....9$$

2,v1,v2,v3 ≥ 0
1=units (countries) included in the measurement

In measuring energy efficiency, we used total energy consumption for each GCC country without differentiating energy source types because all of these countries depend on fossil fuels, mainly oil. Based on World Bank data (2012), all GCC countries derive 100 percent of their energy consumption from fossil fuels, United Arab Emirates, Saudi Arabia and Bahrain use less than 1 percent of alternative sources of energy.

V. Data and Methodology

A. The Data

The data sources which are used in the modeling are secondary. In performing the unit root, cointegration and causality tests between the GDP and energy consumption, we used time series data from 1980 to 2009. The GDP data obtained from the IMF (2011) and energy consumption data was obtained from the World Bank (2012).

In performing the DEA to measure the energy efficiency, the data of 2001, 2003, 2005, 2007 and 2008 is used for three inputs (capital, labor force, and energy consumption) and one output (GDP). For all input, World Bank (2012) data was used and IMF (2011) data was used for the output. The description of data is presented in tables 3, 4, and 5.

Table 3: Data Used for Causality Test

Variables	*Descriptions*
Energy consumption	Energy use in (tons of oil equivalent), World Bank (2012)
GDP	Gross domestic product based on local constant price (in billions of national currency units), IMF (2011) World Economic Outlook

Table 4: Data Used for DEA Measurement

Variables	*Descriptions*
Energy consumption	Energy use (ton of oil equivalent), World Bank (2012)
Capital	Gross capital formation (current US$), World Bank (2012)
Labor force	total labor force, World Bank data
GDP	Gross domestic product based on purchasing-power-parity (PPP) valuation of country GDP (billions in current international dollar), IMF (2011) World Economic Outlook

Table 5: Summary of Inputs and Output Variables for Six GCC Countries and Three Developed Countries, 1980-2009

Variables	*2001*	*2003*	*2005*	*2007*	*2008*
Mean Input 1- Capital (billions in current US$)	27.8	35.7	51.8	72.8	89.7
Stdev Input 1- Capital (billions in current US$)	28.1	36.5	55.1	69.1	88.4
Mean Input 2- Energy consumption in (tons of oil equivalent)	38984.6	42166.6	46966.8	49625.1	52784.4
Stdev Input 2- Energy consumption in (tons of oil equivalent)	37385.6	41295.2	47192.8	46920.5	49539.7
Mean Input 3- Labor (in thousands)	3059.8	3251.0	3491.5	3823.9	4004.7
Stdev Input 3- Labor (in thousands)	3119.9	3312.0	3507.8	3687.4	3766.6
Mean Output-GDP (billions in current US$)	179.8	199.8	232.9	269.4	286.3
Stdev Output-GDP (billions in current US$)	169.5	187.6	212.8	237.8	248.4

B. The Methodology

The Augmented Dickey Fuller (ADF) (1979) and Phillips-Perron (1988) tests were implemented to assess the unit root. While performing the ADF test, the Schwarz (1987) Information Criterion was used for the lag length including the trend and intercept in the equation. The Phillips-Perron test was performed using automatic bandwidth selection of Newey-West (1987). This was implemented by including trend and intercept as well. For the cointegration test, the Johansen maximum likelihood cointegration test was employed (Masih and Masih, 1996).

After conducting the unit root and cointegration tests, we continued by testing the causality between energy consumption of the GDP by using Granger Causality Test (Granger, 1969). In order to test the causality from energy consumption to GDP, the following log-linear equation is estimated for GCC countries over the period from 1990-2009:

$$Lny_t = \underline{\lambda}_0 + \underline{\lambda}_1 \, 7Lny_{t-1} + \underline{\lambda}_3 \, Lnx_{t-1} + \mu, \qquad (5)$$

where

y_t = real per capita GDP in period t

y_{t-1} = real per capita GDP in period t-1

y_{t-1} = layed value for per capita energy consumption in period 5-1

μ = error term

The presence of Granger-causality depends on the significance of X_{x-I} term in Equation (5); energy consumption causes GDP if the current value of GDP is predicted better by including lagged value of energy consumption.

In measuring the performance of energy efficiency among GCC countries, DEA methodology was used. Various indices have been used in comparing performances of countries across the world, e.g., the human development index and the global competitiveness index, by considering some relevant attributes in developing them (Savic and Martic, 2001 and Thore, 2008). We can classify them as fixed weight schemes since they combine performances in terms of various attributes using pre-fixed weights, which may be subjectively chosen. The advantage of DEA vs. fixed weight schemes is that the weights are not subjective but determined using linear programming (Ramanathan, 2006). The DEA approach computes these weights that maximize the efficiency score of a country subject to the efficiencies of other countries (calculated using the same set of weights) falling between 0 and 1.

Despotis (2005) considers DEA as a mathematical programming methodology based on the Frontier approach. It has been successfully employed to study the comparative performance of units that consume similar inputs and produce similar outputs. The units are generally referred to as Decision Making Units (DMUs). When we are assessing the performance of nations, DEA combines performances of countries in terms of several desirable and undesirable attributes into a single scalar measure, called the efficiency score. Countries that have unit efficiency scores of 1 are considered efficient, with the highest value of desirable attributes and the lowest values of undesirable attributes. Countries with efficiency scores of less than one are considered to operate sub-optimally for a given set of variables.

There are two possible assumptions that could be made while computing efficiency scores using DEA, namely constant returns to scale (CRS) and variable returns to scale (VRS). The assumption of CRS occurs when an increase in all inputs (i.e., increase in terms of undesirable attributes) by 1 percent leads to an increase in all outputs (i.e., increase in terms of desirable attributes) by 1 percent, while the assumption of VRS is for situations when the CRS assumption is not satisfied. The VRS efficiency of a DMU measures only technical efficiency, while CRS efficiency accounts for both technical efficiency and efficiency loss, when the DMU does not operate in its most productive scale size. The scale efficiency is the ratio of CRS to VRS scores. The scale efficiency of 1 would be for DMU which operates in its most productive size (Savic, 2001).

Taqi and Shah (2006) considered DEA as a non-parametric linear programming based methodology originally introduced by Charnes *et al.* (1978). Choosing the DMUs as the entities responsible for converting inputs into outputs is the key element in DEA. It compares each DMU based on its input and output factors with all other similar DMUs taken into consideration. Consequently, choosing outputs and inputs is a very important activity in the DEA process.

DEA can be used to obtain an overall measure of efficiency for each DMU, given the choices and the observed values of the inputs used and the outputs produced by each DMU. By using mathematical models, we obtained efficiency results depending on the performance attained by all of the DMUs. Thus, we can say that the efficiency measures through DEA are obtained by comparing them relatively with other DMUs. For example, one DMU, designated as DMU1, is being evaluated relative to some other DMUs which produced the same amount of output as DMU1 but used smaller levels of input. Then, DMU1 would be rated as inefficient relative to the other DMUs, where differences in their inputs would represent sources and amounts of inefficiency in DMU (Nordin, 2007).

VI. Results and Analysis

A. Causality Test

For policy purposes, the causality relationship between economic growth and energy consumption will be tested using a unit root test to find whether or not there is a unit root effect in the series. The result is presented in Table 6.

Table 6: Unit Root Test Results

Series	Augmented Dickey Fuller Test			Phillips-Perron Test	
	Level	1st difference	2nd difference	Level	1st difference
Saudi Arabia-Energy consumption	non stationary	stationary		non stationary	stationary
Saudi Arabia GDP	non stationary	stationary		non stationary	stationary
Bahrain-Energy consumption	non stationary	non stationary	stationary	non stationary	stationary
Bahrain-GDP	non stationary	stationary	stationary	non stationary	stationary
Kuwait- Energy consumption	non stationary	stationary		non stationary	stationary
Kuwait-GDP	non stationary	stationary		non stationary	stationary
Qatar- Energy consumption	non stationary	non stationary	stationary	non stationary	stationary
Qatar-GDP	non stationary	non stationary	stationary	non stationary	stationary (at 10%)
Oman- Energy consumption	non stationary	stationary		non stationary	stationary (at 10%)
Oman-GDP	non stationary	stationary		non stationary	stationary
UAE- Energy consumption	non stationary	stationary		non stationary	stationary
UAE-GDP	non stationary	stationary		non stationary	stationary
Panel- Energy consumption	non stationary	stationary		non stationary	stationary
Panel-GDP	non stationary	stationary		non stationary	stationary

Based on the unit root test, all the series are non-stationary at the level, since they contain trends. Taking the first difference for all of them, they become stationary at first difference. Since the stationarity of the series at the same level is a necessary condition in order to get valid result of causality test, then the causality test can be continued.

However, the co-integration test between the GDP and energy consumption for each country is shown in Table 7.

Table 7: Co-integration Test Results

Countries	*Cointegration between energy and GDP*
UAE	Not cointegrated
SAUDI ARABIA	Cointegrated
QATAR	Cointegrated
OMAN	Cointegrated
KUWAIT	Not cointegrated
BAHRAIN	Cointegrated
PANEL	Cointegrated

Although the results for the UAE and Kuwait showed that energy consumption and GDP are not cointegrated at a 5 percent confidence level, further testing of the causality between the two series (energy consumption and GDP) is not a necessary condition for the causality test. However, correlation does not necessarily imply causation.

Based on Granger (1988), whether x causes y in Equation (5) depends on how much of the current y can be explained by past values of y and then to see whether adding lagged values of x can improve the explanation. It is said that y is Granger-caused by x if x helps in the prediction of y, or equivalently if the coefficients on the lagged x's are statistically significant. The result of applying the Granger Causality test on the relationship between GDP and energy consumption is presented in Table 8. The results are confirmed by doing F-tests for the coefficients of the independent results including error terms at a 5 percent significance level, while R-squares range from 80 percent to 95 percent.

Table 8: Granger Causality Test Results

Granger Causality	*Saudi Arabia*	*Bahrain*	*Kuwait*	*Qatar*	*Oman*	*UAE*	*Panel*
GDP cause energy consumption	no	yes	yes	no	no	no	yes
Energy consumption cause GDP	yes	no	no	yes	yes	yes	no

It is noted that there is a strong causality from energy consumption to GDP for Saudi Arabia. Results for Oman are similar to Saudi Arabia, while Qatar and the UAE show a moderate causality from energy consumption to GDP. The result for Bahrain shows the opposite direction that GDP causes energy consumption, while Kuwait somehow tends to have stronger causality running from GDP to energy consumption. For the panel of GCC, causality runs from GDP to energy consumption, which is consistent with previous research by Al-Iriani (2006) and Mehrara (2007).

Bahrain and Kuwait tend to be in line with developing countries when causality runs from GDP to energy consumption, while the other countries showed that they are close to what was found in the developed countries by Chontanawat *et al.* (2006).

B. Energy Efficiency

After performing the causality tests, the measurement of energy efficiency is performed using the input oriented DEA with CRS envelopment analysis.

In order to have benchmark for comparison, three other OECD countries were added in the measurement. We selected efficient countries based on the results of measurements conducted by Zhou and Ang (2008) for 21 OECD countries. The result of energy efficiency measurement using Model I is presented in Table 9.

Table 9: Energy Efficiency Measure Using Model I

No.	*DMU Name*	*2001*	*2003*	*2005*	*2007*	*2008*
1	UAE	0.41	0.45	0.48	0.40	0.35
2	SAUDI ARABIA	0.49	0.46	0.43	0.42	0.32
3	QATAR	0.55	0.53	0.64	0.65	0.41
4	OMAN	0.54	0.48	0.46	0.45	0.46
5	KUWAIT	0.45	0.55	0.51	0.45	0.52
6	BAHRAIN	0.47	0.46	0.46	0.44	0.45
7	AUSTRALIA	0.60	0.59	0.57	0.54	0.54
8	NORWAY	0.79	0.78	0.80	0.76	0.72
9	SWITZERLAND	1.00	1.00	1.00	1.00	1.00

Saudi Arabia and Bahrain did not show significant improvement and were still in the inefficient rankings compared to others countries as measured in Table 9. Qatar showed significant improvement, while the UAE's improvement was slightly slow. Oman's performance has declined since 2007, and Kuwait exhibited significant improvement to become the most efficient country in the GCC surpassing Oman.

By comparing the energy efficiency of GCC countries with energy efficiency in developed countries, it seems that the GCC is still far behind but has high potential for energy preservation. Comparing the results of the energy efficiency measurement in Model I with the efficiency findings using the energy intensity in Figure 2, the results are consistent.

The advantage of using the energy intensity of Figure 2, is that improvement in country efficiency can be shown for recorded years while Model I, gives efficiency improvement of GCC countries relative to other depicted countries at one time period.

In Model II, instead of using only energy consumption as the only input, labor and capital as other economic features were added in order to measure energy efficiency within an economic perspective.

Measurement results using Model II are shown in Table 10. Even classified as inefficient in terms of energy consumption, Saudi Arabia appears in the efficient frontier in economy-wide performance since 2005. Qatar and Kuwait have maintained their efficient economy-wide relative to others as in Model I, while Oman has been inefficient since 2007. The UAE and Bahrain have shown more room for improvement to attain economic efficiency.

Table 10: Energy Efficiency Measure Using Model II

No.	*DMU Name*	*2001*	*2003*	*2005*	*2007*	*2008*
1	UAE	0.45	0.85	0.86	0.77	0.75
2	SAUDI ARABIA	0.42	0.84	1.00	1.00	1.00
3	QATAR	0.51	1.00	1.00	1.00	1.00
4	OMAN	0.56	0.99	1.00	0.86	0.82
5	KUWAIT	0.42	1.00	1.00	1.00	1.00
6	BAHRAIN	0.45	0.71	0.74	0.81	0.70
7	AUSTRALIA	0.54	0.90	0.87	0.86	0.84
8	NORWAY	0.72	1.00	1.00	1.00	1.00
9	SWITZERLAND	1.00	1.00	1.00	1.00	1.00

In comparison with efficient developed countries, Model II also shows that GCC countries have to improve their economic energy efficiency. It is noted that results from Model I and Model II differ substantially. This is due to the structural difference between Model I and Model II, where the latter explains economic efficiency more than energy efficiency. Including labor, and capital as a factor of production in Model II, has also changed the model specifications and, ultimately, the results. Furthermore, the structural and policy differences among GCC countries are clearer in Model II which affected its results and caused some discrepancies between the results from Model I and Model II.

VII. Conclusion and Policy Implications

With increased pressure on scarce water resources and high energy consumption, the GCC will be adversely affected by climate change and rising air pollution vulnerabilities. Therefore, GCC countries have directed their energy policy to energy efficiency policies. Recently, research on alternative energy has been encouraged with more strategic movement toward energy conservations. Table 11, shows the policy implications of the results.

Table 11: Energy Efficiency—Results and Policy Implications

Countries	*Model II*	*Model I*	*Causality*	*Policy Implication*
Saudi Arabia	Efficient	Inefficient	Energy consumption to GDP	It seems that Saudi Arabia depends significantly on oil consumption in its economy. Their economy is efficient, but their energy consumption is not efficient compared to other GCC countries. Energy consumption in Saudi Arabia is very high since they have very cheap energy. Increasing oil prices (reduce subsidy) to reduce the oil consumption will obviously reduce CO_2 emissions. Since the causality strongly runs from EC to GDP for Saudi Arabia, then it needs to complement the strategy by providing alternative power environment-friendly sources of energy like solar to substitute oil, so that the effect on the GDP is controlled.
Bahrain	Inefficient	Inefficient	GDP to energy consumption	Bahrain's economy is inefficient due to its inefficient use of energy. Thus, energy conservation policy would be appropriate for Bahrain, since the causality runs from GDP to energy consumption. In fact, the more efficient their energy use, the more efficient the economy will be.
Kuwait	Efficient	Efficient	GDP to energy consumption	For Kuwait, it is efficient for both energy and economic efficiency compared to other GCC countries. Since the strong causality runs from GDP to energy consumption in this country, it is suggested for the government to implement energy conservation policy to become more energy efficient which eventually will become more efficient in the economy as well as toward that of more developed countries that were used as benchmark.
Qatar	Efficient	Inefficient	Energy consumption to GDP	The economy of Qatar is efficient compared to other GCC countries, and the trend for its energy efficiency is improving. Based on their causality test, they have weak causality which runs from EC to GDP that will not have a great negative effect on their economy if they implement energy conservation policy.
Oman	Inefficient	Inefficient	Energy consumption to GDP	Unlike in other GCC countries, the trend of energy efficiency is decreasing for Oman. It started to become inefficient in using energy and the economy has tended to become inefficient, as well since 2007. By implementing energy conservation policy, Oman needs to also adopt an alternative energy policy to replace the oil dependency in its economy, since we found strong causality running from energy consumption to GDP.
UAE	Inefficient	Inefficient	Energy consumption to GDP	Both the economy and energy use of the UAE is classified as inefficient compared to those of other GCC countries. They can improve their efficiency by implementing energy conservation policy since they have only weak causality running from energy consumption to GDP.

Increasing international concerns over global warming and climate change have brought a significant dilemma for some countries, especially developing countries. It becomes important for GCC policy makers to realize the importance of energy efficiency. Some indicators were developed to measure energy efficiency, such as energy intensity and economic-thermodynamics to assist in quantifying such measures. In this paper, we applied linear programming techniques to measure and compare energy efficiency of the GCC countries.

In order to complement the results, the causality test between energy consumption and GDP for each GCC country and for all GCC countries as a panel has been conducted. This type of test will be useful for determining the appropriate policy to adopt to achieve energy efficiency without crippling economic growth.

For further research, a sectoral energy analysis related to the GDP of GCC countries should be performed to develop sound policies for each sector without harming the economic growth of the country.

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