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# Impact of Energy Consumption on Economic Growth in Major Organization for Economic Cooperation and Development Economies (1977-2014): A Panel Data Approach

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**ABSTRACT**

This paper is aimed at assessing the impact of energy use growth on economic growth in the major economies of the Organization for Economic Cooperation and Development during the period 1977-2014. To do this, a Granger causality analysis among relevant variables is carried out and, subsequently, a panel data model is estimated with the generalized method of moments. The main empirical finding is that real gross domestic product per capita growth is positively affected by the growth rate of energy use per capita in the following studied economies: Germany, Australia, Austria, Belgium, Canada, Denmark, Spain, USA, Finland, France, Greece, Holland, Italy, Luxembourg, Norway, Portugal, Sweden, and New Zealand.

**Keywords:** Energy Consumption, Economic Growth, Panel Data Analysis
**JEL Classification:** C23, O41, Q43

## 1. INTRODUCTION

The relationship between energy and economic growth has been for a long time an important issue since energy contributes to the expansion of goods and services increasing productivity by encouraging the use of machinery and equipment in the production process serving to escalating businesses. The causal links between the energy sector and the output growth has been examined in many investigations, mainly empirical. The role of the energy sector in boosting economic activity has been studied since Tatom's (1981) pioneer paper, and the succeeding work from Denison (1985). In subsequent research, some authors argue that energy consumption causes economic growth, while others indicate that the impact is not significant and energy consumption is determined by the levels of the product. In this regard, there is a general concern with the direction of causation and its magnitude since many empirical results are partial and incomplete.

Most of the empirical literature addresses the link between energy and economic growth using different techniques, which are, on the one hand, the time series approach: Vector autoregressive (VAR), Granger causality, and cointegration that can be found in: Stern (1993), Asafu-Adjaye (2000), Stern (2000), Hamilton (2003), Soytas and Sari (2003), Fatai et al. (2004), Jumbe (2004), An et al. (2014), Ayres and Voudouri (2014), and many others. On the other hand, we have the investigations that used panel data as those from: Azali et al. (2001), Lee (2005), Lee and Changb (2007), Al-Mulali and Che-Sab (2013), Mohammadi and Parvaresh (2014), Kasperowicz (2014), Bretschger (2015), and Jebli et al. (2016). Independently of the used approach, most of them find a positive relationship between the energy sector and economic growth. A detailed literature survey can be found in the study of Ozturk (2010).

In this research the impact of the energy sector on economic growth is examined in 18 member countries of the Organization for Economic Cooperation and Development (OECD). Specifically, it will be assessed the impact on gross domestic product (GDP) per capita in US dollars from energy use per capita during 1977-2014. This paper carries out an analysis of panel data with information provided by the World Bank in order to find empirical evidence on the links between the energy sector and output growth. Finally, on the basis of the empirical findings, this research establishes some simple recommendations that will allow the energy sector to raise economic growth.

Referring to the current state of the subject, this work is distinguished in the following aspects: (1) It focuses on some of the major OECD economies (Germany, Australia, Austria, Belgium, Canada, Denmark, Spain, USA, Finland, France, Greece, Holland, Italy, Luxembourg, Norway, Portugal, Sweden, and New Zealand); (2) it has a greater availability of data from the past; (3) it provides an analysis of static and dynamic data panel that allows a greater number of countries, variables and periods; and finally (4) it corrects problems of multicollinearity and autocorrelation.

The rest of the paper is organized as follows: Section 2 deals with a brief review of the literature on the interrelation of the energy sector and economic growth; section 3 presents the descriptive statistics of the relevant variables used in this research; section 4 carries out an econometric analysis of panel data; section 5 shows and discusses the main empirical results in the analyzed countries; finally, section 6 provides conclusions and policy recommendations derived from this investigation, and acknowledges possible limitations.

## 2. A BRIEF REVIEW ON ENERGY SECTOR AND ECONOMIC GROWTH

The relation between the energy sector and the expansion of production has been widely studied and examined from multiple approaches and points of view. The role of energy prices in increasing economic activity has been studied since Tatom's (1981) pioneer work, and the subsequent research from Denison (1985). The importance of the energy sector for the economic performance has been analyzed by: Maddison (1987), Stern (1993), Asafu-Adjaye (2000), Soytas and Sari (2003), Lee (2005), Lee and Changb (2007), Acaravci and Ozturk (2010), Tugcu et al. (2012), Al-Mulali and Che-Sab (2013), Menegaki and Ozturk (2013), An et al. (2014), Mohammadi and Parvaresh (2014), Ayres and Voudouri (2014), Kasperowicz (2014) and Bretschger (2015). Most these studies find that the energy sector drives economic activity.

The effects of prices of energy resources on economic growth has been studied by Tatom (1981) in six countries: United States, Germany, Japan, France, Canada, and Netherlands. This author examines the effects of the increase in energy prices in aggregate supply. Tatom estimates a production function Cobb-Douglas type for each of these countries and finds a strong correlation between energy prices and output. On the other hand, Maddison (1987) emphasizes that the 1973 oil crisis increased oil prices which caused: An augment in inflation, a problem of balance of payments, a decrease in gross national product, and a deteriorating of the terms of trade in industrialized countries. Furthermore, Maddison studies a long period of performance of industrialized economies and finds that energy consumption grows at lower rates than GDP. He also exhibits a significant energy saving and effort of energy sustainability in more advanced economies.

The causal relationship between energy consumption and GDP in the United States has been studied by Stern (1993) during the period 1947-1990 by using a VAR model considering GDP, capital, employment and energy consumption. After carrying out a Granger causality test among these variables, he concludes that although there is no evidence that energy consumption causes GDP, a measure of end-use energy adjusted for the change in fuel composition does not causes GDP.

Moreover, Asafu-Adjaye (2000) studies the causal relationship between energy consumption and income in India, Indonesia, Philippines and Thailand, by using cointegration and error correction techniques. His research results indicate that in the short run Granger causality is unidirectional, it goes from energy to GDP for India and Indonesia, while causality is found from energy to income for Thailand and the Philippines. Also, Soytas and Sari (2003) study the relationships between energy consumption and GDP and revisit the causal link between these two variables in the top 10 emerging markets and the G-7. They found (1) bidirectional causality in Argentina, (2) causality of GDP to energy consumption in Italy, and Korea, and (3) causality of energy consumption to GDP in Turkey, France, Germany, and Japan. Finally, they conclude that saving energy can hurt economic growth in the latter four countries.

Lee (2005) studies the causal link between energy consumption and GDP in 18 developing countries during the period 1975-2001. He uses unit root and cointegration tests with panel data on the basis of an error correction model. He finds a cointegration relationship between long-term energy consumption and GDP, and evidence of causality between energy consumption and GDP in the short run. He also indicates that energy savings can harm economic growth in developing countries. Also, Lee and Changb (2007) study the relationship between per capita energy consumption and per capita GDP in a sample of 22 developed countries and 18 developing countries. By using panel data and a VAR model, they find evidence of stationarity among variables in both groups (developed and developing countries).

Al-Mulali and Che-Sab (2013) analyze the impact of total consumption of primary energy and $CO_2$ emissions in economic development in 16 developing countries by using panel data models in the period 1980-2008. They find a long-term relationship among the total primary energy consumption, $CO_2$ emissions, and economic development in the countries under investigation. They also emphasize that total primary energy consumption has a positive causal relationship with economic development and other economic issues that play an important role in achieving high economic performance with the consequence of further contamination.

On the other hand, An et al. (2014) study the asymmetric effect of oil price shocks on real economic activity in the US by means of a non-linear model and simulation methods. These authors analyze effects (positive and negative) of the oil crisis on macroeconomic performance through impulse-response function. They find that the negative impacts of oil prices are larger than the positive effects. They show that their results are robust for different specifications of delays.

Mohammadi and Parvaresh (2014) examine the dynamics of the relations between short- and long-term energy consumption and production in a panel of 14 oil exporting countries in the period 1980-2007 by using unit root tests with panel data. These authors cannot reject the non-stationarity between the two variables. They also explore the relationship by fixed and random effects (REs) models and crosscut effects. These authors find a stable relationship between energy consumption and output with bidirectional causality in both long and short term.

Ayres and Voudouri (2014) study the nonlinear relationships among capital, labor, energy, and growth in the US, UK and Japan. They find that the elasticities of the product and capital, and labor and energy are unpredictable over time. They consider that the provision of adequate and affordable amounts of energy is a necessary condition for economic growth. On the other hand, Kasperowicz (2014) examines the relationship between energy consumption and economic growth in 12 European countries from 2000 to 2012. After modeling with panel data the relationships among growth rates of energy consumption, growth rates of gross fixed capital formation, and gross fixed investment, the author finds a positive relationship between energy consumption and economic growth in the studied countries.

Bretschger (2015) analyzes the effects of energy prices on economic growth in 37 developed countries during 1975-2004. This author use panel data with simultaneous equations to show that the increase in energy prices is not a threat to economic development in the long-term. He also finds that a decrease in energy input induces investment in physical and human capital and knowledge, which promotes output growth. In short, the energy sector helps operators to expand production of goods and services, it also contributes to higher productivity; all of the above exceeds the negative effects in expanding businesses.

## 3. DESCRIPTIVE STATISTICS OF THE VARIABLES UNDER STUDY

The data used in this research were obtained from the World Bank: Per capita GDP and per capita energy use for the period 1977-2014. These variables are expressed in US dollars at constant 2005 prices. The data available provide a balanced panel, and the studied period is restricted to available data. The panel includes 18 OECD countries. The notation and statistics of the variables are presented in Table 1.

Table 1 shows the variables that will be used in this research, as well as their averages, standard deviations, and minimum and maximum levels. For the sample of 18 members of OECD economies, the average GDP per capita is 31,882.77 USD, the standard deviation is 1,212,868.47 USD, with a minimum of 9614.36 USD and a maximum of 86,129.38 USD. The average energy use per capita in the chosen 18 industrialized economies is 4636.28 USD, with a standard deviation of 1941.71 USD, a minimum of US $ 854.36 and a maximum of US $ 11,096.00. Most of the research regarding energy sector and economic growth predict a positive correlation. In what follows, logarithm of real GDP per capita will be denoted by lgdpper and logarithm of energy use per capita in USD is denoted by lusenerg. Figure 1 reinforce this argument. The results from a graphical statistical analysis reveal that the growth rates of output and energy use may be positively related for the economies under study.

Figure 1 shows the dynamics of the growth rate of energy use per capita related to the growth rate of real GDP per capita for the selected 18 economies. It is observed a positive relationship between these two variables, which indicates that further expansion in energy used per person tends to raise real GDP per person. In short, the above graph supports that energy use may be directly associated with output growth.

## 4. PANEL DATA ANALYSIS

The use of panel data analysis is becoming more common because it is very useful for applied research comparing several countries. Panel data stands for a sample of characteristics that countries have over time, i.e., it is a combination of time series data with a cross section analysis. The general model intended to be estimated is given by:

$$y_{it} = \alpha y_{it-1} + \beta X_{it} + u_{it} \quad (1)$$

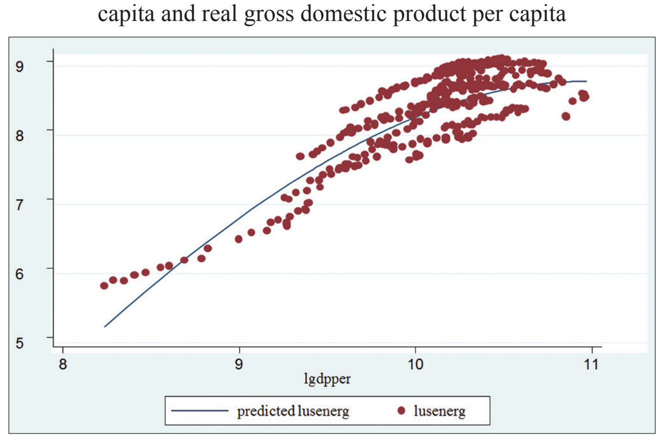
Where $y_{it}$ is the dependent variable that changes depending on i (the number of countries) and t (the number of years), $y_{it-1}$ is the lagged dependent variable, $X_{it}$ are exogenous variables, and $u_{it}$ stands for random perturbations. In this case, estimates from ordinary least squares (OLSs) will be, usually, biased. To avoid this, alternative

**Table 1: Statistics of the study variables**

| Variable | Notation | Average | Deviation | Minimum | Maximum |
|---|---|---|---|---|---|
| GDP per capita | gdpper | 31882.77 | 12868.47 | 9614.36 | 86129.38 |
| Energy use per capita | usenerg | 4636.28 | 1941.71 | 845.36 | 11096.00 |

Source: Authors' own elaboration with data from World Bank, Stata 11. GDP: Gross domestic product

**Figure 1:** Relationship between the growth rates of energy use per capita and real gross domestic product per capita




Source: Authors' own elaboration with data from World Bank, Stata 11 models to the pooled regression are proposed: Fixed effects (FE) and RE models, which will be discussed later.

The use of panel data has several advantages because it examines a larger number of observations with more and better information, support a greater number of variables, and data has less multicollinearity between the explanatory variables, as well as greater efficiency in the estimation. Another advantage is that more data can be included to track all the countries (observation units). It also overcomes the problem of omitted variables, because they may be eliminated by taking differences in variables that do not change over time[1]. Of course, the panel data also has disadvantages and limitations as the data are more complex and no heterogeneity is treated. If all the qualities of the country are not observable, then errors will be correlated with the observations and the OLS estimators will be inconsistent. The FEs model involves fewer assumptions about the behavior of errors. In this case, it is assumed that the model is:

$$y_{it} = \alpha y_{it-1} + \beta X_{it} + \epsilon_{it} \qquad (2)$$

Where $\epsilon_{it} = v_i + u_{it}$. Here, the error $\epsilon_{it}$ can be decomposed into two parts, a fixed constant for each country $v_i$ and another random term $u_{it}$ that meets the requirements of OLS, which is equivalent to performing a general regression giving each individual a different origin point (ordinate).

The RE model has the same specification as the FEs with the exception that the terms $v_i$, instead of being fixed values for each country, they are random variables with mean $E[v_i]$ and variance $Var(v_i) \neq 0$. Thus, the model specification becomes:

$$y_{it} = \alpha y_{it-1} + \beta X_{it} + v_{it} + u_{it} \qquad (3)$$

Where now $v_i$ is a random variable. In general, the RE model is more efficient, but less consistent than FE. In order to estimate the dynamic panel data, the generalized method of moments (GMMs) will be used; see, for example, Arellano and Bond (1991). The difference MGM estimator developed by Arellano and Bover (1995) is based on differences regressions to control unobservable effects. Subsequently, previous observations of the explanatory variables and lags of the dependent variables are treated as instruments.

The difference GMM estimation has some disadvantages as shown in Blundell and Bond (1998), particularly when the explanatory variables are persistent over time. In this case, lagged levels of the above mentioned variables are weak instruments for the difference equation. Moreover, this approach skews the parameters if the lagged variable (in this case the instrument) is very close to being persistent. These authors introduce new moments on the correlation of the lagged variable and the error term. To do so, conditions of covariance between the lagged dependent variable and the difference of the errors, as well as the change in the lagged dependent variable are added, and the error level has to be zero. This estimator also relates a set of equations instrumented with lags of the difference equations (Bond, 2002).

1 For a more detailed panel data analysis see Baltagi (1995) analysis.

GMM system ensures consistent estimates for the parameters even when endogeneity problems are unobserved. This approach will be used to estimate the parameters as proposed by Arellano and Bover (1995) and, subsequently, several improvements from Blundell and Bond (1998) will be also implemented in this research. The estimator thus obtained has advantages over other estimators as FE. In general, GMM system optimal estimator has the following form:

$$\hat{\theta}_{GMM} = \begin{pmatrix} \hat{\alpha}_{GMM} \\ \hat{\beta}_{GMM} \end{pmatrix} = \left[ \left(y^*_{-1};\, x^*\right)' z^* V_N^{-1} z^{*'} \begin{pmatrix} y^*_{-1} \\ x^* \end{pmatrix} \right]^{-1} \left[ \left(y^*_{-1};\, x^*\right)' z^* V_N^{-1} z^{*'} y^* \right] \qquad (4)$$

Equation (4) is a system consisting of a regression containing information on levels and differences in terms of conditions of moments:

$$E[X_{i,t=s}(v_{it} - v_{i,t=1})] = 0, \text{ for } s \geq 2;\ t = 3,\dots,T \qquad (5)$$

Which will be applied to the first part of the system. The regressions in differences, which are written below, are applied to the second part i.e., the regression in levels:

$$E[(X_{i,t=s} - X_{i,t-s-1})(v_{it} - v_{i,t=1})] = 0, \text{ for } s = 1;\ t = 3,\dots,T \qquad (6)$$

The lags of the variables in levels are used as instruments in the regression in differences. Only the most recent differences are used as instruments in the regression in levels. The model generates consistent and efficient estimates of the coefficients. In this case,

$$y_i^* = \alpha y_{i-1}^* + \beta x_i^* + v_i^* \qquad (7)$$

And the error component $v_i$* is given by,

$$v_i^* = \begin{bmatrix} \Delta v_i \\ u_i \end{bmatrix} \rightarrow \begin{cases} \Delta v_i = [\Delta v_{i3}, \Delta v_{i4}, \dots, \Delta v_{iT}] \\ u_i = [\Delta u_{i2}, \Delta u_{i3}, \dots, \Delta u_{iT}] \end{cases} \qquad (8)$$

The array of instruments for differences in the model includes information on the explanatory variables and the lagged dependent variable in the following way:

$$Z_i = \begin{bmatrix} y_{i0} & x_i^2 & 0 & 0 & 0 & \dots & 0 & 0 & 0 & \dots & 0 & 0 \\ 0 & 0 & y_{i0} & y_{i1} & x_i^3 & \dots & 0 & 0 & 0 & \dots & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \dots & 0 & 0 & 0 & \dots & 0 & 0 \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ 0 & 0 & 0 & 0 & 0 & \dots & y_{i0} & y_{i1} & y_{i2} & \dots & y_{T-2} & x_i^T \end{bmatrix} \qquad (9)$$

While the matrix of instruments for the equation in levels only considers the explanatory variables without the lagged dependent variable,

$$Z_i = \begin{bmatrix} x_i^2 & 0 & 0 \ldots & 0 \\ 0 & x_i^3 & 0 \ldots & 0 \\ 0 & 0 & x_i^4 \ldots & 0 \\ \ldots & \ldots & \ldots\ldots & \ldots \\ 0 & 0 & 0 \ldots & x_i^T \end{bmatrix} \quad (10)$$

The matrix of instruments takes the following form:

$$Z = \begin{bmatrix} Z_1 \\ Z_2 \\ Z_3 \\ \vdots \\ Z_N \end{bmatrix} \quad (11)$$

Finally, the $V_N$ matrix is the covariance matrix of valid time constraints for the optimal case:

$$V_N = E[Z'\Delta v \Delta v' Z] \quad (12)$$

Additional tests to ensure the proper functioning of MGM are the first and second orders Sargan tests of over-identification that considers the statistic:

$$s = \hat{v}' Z\left[\sum_{i=1}^{N} Z_i' \hat{v}\hat{v}' Z_i\right]^{-1} Z'\hat{v} \sim \chi^2(p-k-1) \quad (13)$$

These tests have a $\chi^2$ distribution where v is the vector of residuals, Z the number of conditions imposed, k the number of parameters included in the vector β, and p is the number of columns of the matrix Z. Sargan's tests examine the overall validity of the instruments analyzed.

## 5. ANALYSIS OF EMPIRICAL RESULTS

The first part of this section analyzes the relationship between energy use per capita and GDP per capita growth through Granger causality between these variables to detect the direction of the causality. The second part of the section is concerned with the development of panel data models that allows us to study the relationships between the energy sector and the output per capita growth in a sample of 18 of the most industrialized economies belonging to the OECD: Germany, Australia, Austria, Belgium, Canada, Denmark, Spain, USA, Finland, France, Greece, Holland, Italy, Luxembourg, Norway, Portugal, Sweden, and New Zealand.

All of the variables are expressed logarithms: Log of real per capita GDP will be denoted by lgdpper, and log of per capita energy use in USD is denoted by lusenerg[2]. The analyzed period is 1977-2013, providing 37 years, with 666 observations. In order to examine a balanced panel the econometrics package Stata. 11 will be used. The main results are given below.

### 5.1 Granger Causality

The Granger causality test[3] is a useful tool to examine the correlation between current observations of one variable and past (lagged) values of other variable. In our case, the test establishes as a null hypothesis that there is no causality between energy use and GDP both expressed in per capita terms. The rejection criterion is based, as usual, on the P-value. In particular, the statistics associated with levels ≤0.05 are rejected. The results of Granger causality are shown in the following table.

Table 2 shows that per capita energy use causes per capita GDP lags considering two lags: 1-12 and 15-20, while GDP per capita causes per capita energy use considering two lags: 5-10, 15-30. Estimates indicate that in the first 5 years the direction of causality is stronger from per capita energy use to per capita GDP, an interim period of 6-20 years shows bidirectional causality, while the period from 20 to 32 years shows causality in the Granger sense from GDP per capita to energy consumption per capita. Hence, Granger causality tests initially show that per capita energy use causes per capita GDP, later both variables cause each other, and finally the GDP per capita causes energy use per capita. In summary, most of time, energy use has a positive impact on per capita GDP.

### 5.2. Panel Data Analysis

The aim of this section is to develop a panel data model that allows us to study the relationships between the energy sector and the growth rate of per capita GDP of a sample of the eighteen most industrialized economies in the OECD. As before, variables are expressed in logarithms: Lgdpper is logarithm of real per capita GDP and lusenerg is logarithm of energy use in USD.

Table 3 shows the results of four estimates of static panel data, the first column indicates that the independent variable is the logarithm of energy use with a constant. For all the models, the determination coefficients are estimated and lagrange multiplier and Hausman tests are performed. The second column shows the OLS estimate indicating a positive and significant estimate of log of energy use. Also, notice that the positive constant is significant. Finally, it is important to note $R_2$ is 0.5019, indicating a low coefficient of determination. The third column of Table 2 shows the results of estimates "Between" (BE). Here a significant positive constant is observed; however, in this case, the $R^2$ is 0.3855, which is low.

The fourth column presents the results of the estimation with FE. Appropriate signs (positive) for all variables and the constant are significant; however, a low coefficient of determination is obtained, $R^2 = 0.4793$. The last column shows the results of estimation by EA indicating appropriate signs for all coefficients, including the constant. In this case, coefficients are also significant, but a low $R^2 = 0.5019$ is obtained. The Lagrange multiplier test provides prob > $\text{Chi}^2 = 0.0000$, which indicates that the REs

2 Amounts are expressed in 2005 PPP.

3 For more details see, for instance, Granger (1969).

**Table 2: Granger causality between energy use and per capita GDP**

| Pairwise Granger causality tests | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Null hypothesis** | | | | **Obs** | **F-statistic** | **Lag 1 Probability** | **Lag 2 Probability** |
| lusenerg does not Granger cause lgdpper | | | | 630 | 8.37474 | 0.0039 | 0.0083 |
| lgdper does not Granger cause lusenerg | | | | | 3.445618 | 0.0635 | 0.0178 |
| Lag 3 | Lag 4 | Lag 5 | Lag 6 | Lag 7 | Lag 8 | Lag 9 | Lag 10 |
| Probability | Probability | Probability | Probability | Probability | Probability | Probability | Probability |
| 0.0028 | 0.0262 | 0.0135 | 0.0331 | 0.0506 | 0.0091 | 0.0075 | 0.0056 |
| 0.0618 | 0.0618 | 0.0418 | 0.0003 | 7.E-05 | 0.0036 | 0.0453 | 0.0480 |
| Lag 11 | Lag 12 | Lag 13 | Lag 14 | Lag 15 | Lag 16 | Lag 17 | Lag 18 |
| Probability | Probability | Probability | Probability | Probability | Probability | Probability | Probability |
| 0.0034 | 0.00757 | 0.1234 | 0.0778 | 0.0134 | 0.0132 | 0.0026 | 0.0026 |
| 0.0827 | 0.2162 | 0.3992 | 0.4884 | 0.0153 | 0.0047 | 0.0012 | 0.0008 |
| Lag 19 | Lag 20 | Lag 21 | Lag 22 | Lag 23 | Lag 24 | Lag 25 | Lag 26 |
| Probability | Probability | Probability | Probability | Probability | Probability | Probability | Probability |
| 0.0005 | 0.0002 | 0.4665 | 0.5622 | 0.4878 | 0.4665 | 0.5622 | 0.4878 |
| 0.0005 | 0.0002 | 0.0033 | 0.0112 | 0.0113 | 0.0033 | 0.01122 | 0.0113 |
| Lag 27 | Lag 28 | Lag 29 | Lag 30 | Lag 31 | Lag 32 | Lag 33 | Lag 34 |
| Probability | Probability | Probability | Probability | Probability | Probability | Probability | Probability |
| 0.5222 | 0.5895 | 0.3558 | 0.1889 | 0.2400 | 0.1000 | 0.2018 | NA |
| 0.0129 | 0.0113 | 0.0090 | 0.0205 | 0.0390 | 0.0114 | 0.4539 | NA |

GDP: Gross domestic product

estimation is preferable to OLSs. Finally Hausman[4] test provides prob > $Chi^2$ = 0.0075, indicating that the FE estimation is preferable to RE estimation. Thus, Table 3 summarizes the estimates obtained by four methods of data static panel, i.e., OLS, "between", fixed, and REs. Table 3 also shows information from the Lagrange Multiplier and Hausman tests. The results indicate that the EF estimation is preferred among the four models; however the model fit is quite weak, which does not allow us to explain the impact of energy use growth on output growth. Coupled with the above were performed complementary tests to detect autocorrelation problems. In order to solve autocorrelation problems, we estimate a dynamic panel data model with the GMM. The main results of the estimates of the dynamic panel data are shown in Table 4.

Finally, Table 4 shows the results of estimates from dynamic panel data. The first column indicates that the dependent variable is the logarithm of real GDP per capita, and the explanatory variables are: The lag of the logarithm of real GDP per capita, and the logarithm of energy use per capita. Autocorrelation serial testing of first and second orders and Sargan and Hansen tests were performed. The second column of Table 4 shows the results of the estimation by MGM in differences in one stage. In this case, GDP per capita lagged and energy use growth rate have the appropriate signs and are significant, no serial autocorrelation of first and second order is rejected. The Sargan test rejects the null hypothesis. Hence the overall validity of the instruments is not supported. The third column shows the results of the GMM estimation in differences in two stages. In this case, both GDP per capita lagged and energy use have appropriate signs and are significant. Here, serial autocorrelation of the first order[5] is not rejected, and second order autocorrelation is rejected. The Sargan test rejects the null hypothesis of over-identification, thus the overall validity of the instruments is supported. The fourth column presents estimates for MGM in system in one step. The GDP per capita lagged and energy use growth rate have appropriate signs; however, the energy use is not significant, and the autocorrelation of first and second order are not rejected. The Sargan test rejects the null hypothesis, therefore the general validity of the instruments holds. The fifth column presents estimates by MGM in two-stage system, in which the coefficient of the lagged dependent variable (lpibper.L1) has the expected sign and is significant, coupled with the above energy use in logarithms (lusenerg) has the expected sign and is significant. The first-order autocorrelation is not rejected and the second-order autocorrelation is rejected. The Sargan test rejects the null hypothesis of over-identification and, therefore, the instruments used are valid. GMM estimation in two-stage system is preferable and is the most suitable in relation to other estimates and, therefore, this model is to be chosen to explain the impact of the energy use growth rate on output growth. Estimates indicate that the model of best fit is the estimated GMM in two-stage system, indicating that the current per capita GDP (today) is positively related to lagged GDP per capita (lpibper.L1). Also, GDP per capita growth rate is also related positively to the use of energy growth rate. The estimated MGM in two-stage system model indicates that a 1% increase in energy use will have an impact of 0.4% in per capita GDP in the 18 economies under study during the period 1977-2013.

## 6. CONCLUSIONS

Empirical evidence presented in this research showed that energy use is relevant and has important effects on economic growth. More effort in developing the energy sector will help boost economic activity in the eighteen studied industrialized economies analyzed in this investigation (Germany, Australia,

4 The null hypothesis of the Hausman test is that the estimates of random effects and fixed effects do not differ substantially, if it rejects the null hypothesis is convenient FE; however, when it is not rejected (as in this case) is preferable RE.

5 Usually, the first-order autocorrelation is expected in dynamic models.

**Table 3: Estimates of static panel data**

| Dependent variable: lgdpper | OLS | BE | FE | RE |
|---|---|---|---|---|
| luseneng | 0.8436792 (0.000) | 0.559922 (0.000) | 0.8909117 (0.000) | 0.8436792 (0.000) |
| Constant | 3.255655 (0.000) | 5.623802 (0.000) | 2.861468 (0.000) | 3.255655 (0.000) |
| $R^2$ | 0.5019 | 0.3855 | 0.4793 | 0.5019 |
| ML BP | | | | Prob>Chi²=0.0000 |
| Hausman | | | | Prob>Chi²=0.0075 |
| Number of countries | 18 | 18 | 18 | 18 |
| Number of observations | 666 | 666 | 666 | 666 |

Standard error in parentheses. Source: Authors' own elaboration with data from World Bank, Stata 11. GDP: Gross domestic product

**Table 4: Estimates of dynamic panel data with GMM**

| Dependent variable: lgdpper | GMM difference (one step) | GMM en difference (Two steps) | GMM system (one step) | GMM system (two steps) |
|---|---|---|---|---|
| Lgdpper.L1 | 0.9401069 (0.000) | 0.9375166 (0.000) | 0.9647262 (0.000) | 0.9806815 (0.000) |
| Lusenerg | 0.0757453 (0.000) | 0.0793571 (0.003) | 0.0255295 (0.098) | 0.0041165 (0.000) |
| AR (1) Prob>Z | 0.000 | 0.019 | 0.011 | 0.037 |
| AR (2) Prob>Z | 0.000 | 0.070 | 0.049 | 0.109 |
| Sargan test Prob>Chi² | 0.000 | 0.3451 | 0.000 | 0.872 |
| Number of countries | 18 | 18 | 18 | 18 |
| Number of observations | 630 | 630 | 648 | 648 |

Standard error in parentheses. Source: Authors' own elaboration with data from World Bank, Stata 11. GMM: Generalized method of moments

Austria, Belgium, Canada, Denmark, Spain, USA, Finland, France, Greece, Holland, Italy, Luxembourg, Norway, Portugal, Sweden, and New Zealand).

The Granger causality analysis indicates the existence of a strong relationship between energy use and per capita GDP in both the short and the long-term. Estimates data both static and dynamic panel indicate that the energy sector has a positive influence on increasing output per capita.

The empirical evidence presented here supports the hypothesis of this work: There is a positive impact of increased use of energy in economic growth for the reporting period 1977-2013 for the 18 studied economies. Derived from the present investigation is recommended that decision makers should seek economic policy instruments and incentives to encourage energy sector to boost economic growth. The development of the energy sector should be a key objective for policy and decision makers to promote economic growth.

In view of the main empirical findings, we recommend intense private and public investment and public spending on green energy projects to increase the total energy use. Green energy may contribute in the long run to the extension of output and services increasing encouraging the use of machinery and equipment that do not pollute the environment in the production process leading to sustainable growth. It is also important to point out that environmental policies aimed at reducing energy may have significant negative effects on economic growth in the long-term.

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