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Causal Relationship between Energy Consumption, Economic Growth and CO2 Emissions: A Dynamic Panel Data Approach

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ABSTRACT: Energy plays an important role in economic development worldwide. The increase of energy consumption showed that CO2 emissions in the atmosphere have increased dramatically, and these lead many scientists to push governments of the developing countries to take action for the formulation of environmental policies. Many studies have attempted to look for the direction of causality between energy consumption (EC), economic growth (GDP) and CO2 emissions mainly on developing countries. This paper, therefore, applies the panel unit root tests, panel cointegration methods and panel causality test to investigate the relationship between energy consumption (EC), economic growth (GDP) and CO2 emissions for three countries of Southern Europe (Greece, Spain, and Portugal) covering the annual period 1960-2009. The FMOLS and DOLS are then used to estimate the long run relationship between the variables. The findings of this study reveal that there is a short-run bilateral causal link between the examined variables. However, in the long run, there is a unidirectional causality running from CO2 emissions to energy consumption (EC), and economic growth (GDP) and a bilateral causality between energy consumption and economic growth. This indicates that energy is a force for economic growth both in short and long run as it is driven from economic growth. Moreover, to face the heterogeneity on the three countries of Southern Europe we use the FMOLS and DOLS estimation methods.

Keywords: Energy consumption, Panel cointegration, FMOLS and DOLS Methods.
JEL Classification: C33; O13; Q43

1. Introduction

The global alarm for the threat of the overheating of the planet and the climatic changes was increasing during the last decades. Data from 1960 and 1970 showed the CO2 concentrations in the atmosphere increased rapidly. This situation made climatologists and other scientists to take action mainly for developing countries. Unfortunately, it took many years for the international community to respond to this demand.

On 1988, an Inter-governmental Panel on Climatic Change was formed by the World Meteorological Organization and the United Nations Environment Programme (UNEP). This group presented a first evaluation report on 1990, which depicted the views of some 400 scientists. According to this report, the problem of temperature increase was real and had to be confronted immediately. The conclusions of the Intergovernmental Panel pushed the governments to create the United Nations Framework Convention on Climatic Change (UNFCCC). Regarding the data for the internationals agreements, the negotiation of the Convention was relatively short. It was ready to be signed at the conference of the United Nations for the Environment and Development (better known as

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the summit meeting for the Protection of Earth) on 1992 in Rio de Janeiro. The Framework Convention of the United Nations for the climatic change, as well as the Kyoto protocol that followed, constituted the only international framework for the confrontation of climatic change (IPCC, 2010).

The negotiations for the Kyoto Protocol were hard, as various countries had different interests in the international effort for the solution of world temperature increase. Consequently, many opposite camps were created with deviating views. In particular the following basic camps were created: the **"**Carbon Club**"**: including the following countries, Japan, USA, Canada, Australia, New Zealand, the countries of the OPEC, Russia, Norway, in which in general their interests are affected from the Kyoto Protocol because they would have to decrease their production or turn to different king of fuels.

77 Group (g-77): they are those developing countries such as India and China, that consider they are in a development course and it is against them to commit themselves to restraint their emissions.

Less developed countries: they are 48 countries, which participated all the more actively in the negotiations procedure for climatic change, frequently to defend their particular interests and their fragile economy.

Alliance of Small Island States (AOSIS): it is a coalition of about 43 small island states, which are particularly vulnerable in the rise of sea level. These states are in danger of disappearing from the map because of their small altitude in relation to the level of the sea and therefore their survival is directly in risk.

European Union: It comprises 27 states, and it is the most active group regarding the negotiations for the protection of the environment and continuously presses for the adoption of strict measures.

At last, on 11th of December 1997, a Protocol plan was adopted on Kyoto's international conference for climatic changes. According to this protocol, industrialized countries are obliged to reduce the CO2 emissions of greenhouse effect by 5,2% average in relation to the levels of 1990, during the first "commitment period", which covers the years from 2008 until 2012, and this has been applied since 2005 (UNFCCC 1997).

The question that arises is how scientists will moderate the consequences of climatic change. There are several environmental pollutants which cause climate change, but Carbone dioxide (CO2) is still the dominant gas of total GHG in the world and in 2010 was the highest in history (IEA, 2011).

Exploring the link between energy consumption, CO2 emissions and economic growth has been the subject for many recent studies since the proper use of energy is considered as the best tool to obtain sustainable development.

All countries of EU have sign Kyoto protocol that sets binding obligations to reduce emissions and improve energy use. It is worth mentioning that European countries differ significantly in terms of resources, in economic and geographical size, in population and standard of living. Nevertheless, regional countries are economically weak with restraints to trade on goods and services. Therefore, this paper has a significant contribution for the practice of energy policy on South European countries.

The following figures 1, 2 and 3 present the progress of the three variables, per capita energy consumption, per capita CO2 emissions and GDP per capita for three European countries during the years 1960 – 2009.

From figure 1 we can see that the three countries present an upward trend on per capita energy consumption until the end of 2005 (the year where Kyoto protocol is applied) while they present a decline on energy consumption in the following years.

From figure 2 we can see that CO2 emissions have the same trend as that of energy consumption for the three countries.

From figure 3 we observe that all three countries have an upward trend on GDP per capita until 2008 where economic crisis starts thus there is a reduction on the following years.

From the previous figures we conclude that energy consumption seems to be the principal source of the CO2 emissions since the two curves follow the same tendencies for the three countries of South Europe during 1960-2009. Besides, all three countries exhibit a positive correlation between growth and energy consumption and between growth and CO2 emissions. This conclusion, after examining figures 1-3, encourages us to study the causal relationships between energy consumption, CO2 emissions and economic growth in an integrated frame for the three countries of South Europe.

Figure 1. Energy Consumption per capita (1960-2009)

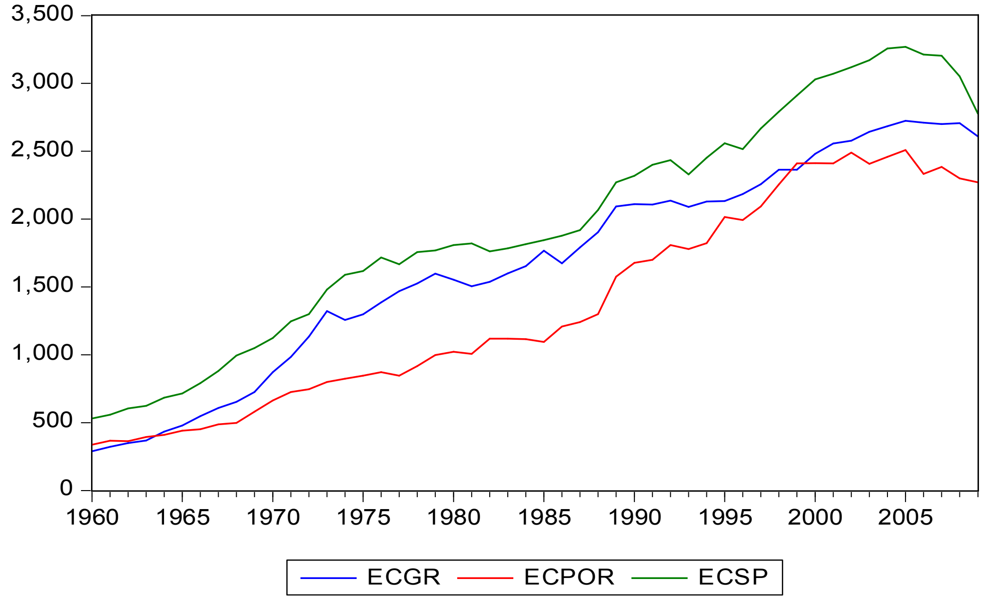


Figure 2. CO2 emissions per capita (1960-2009)

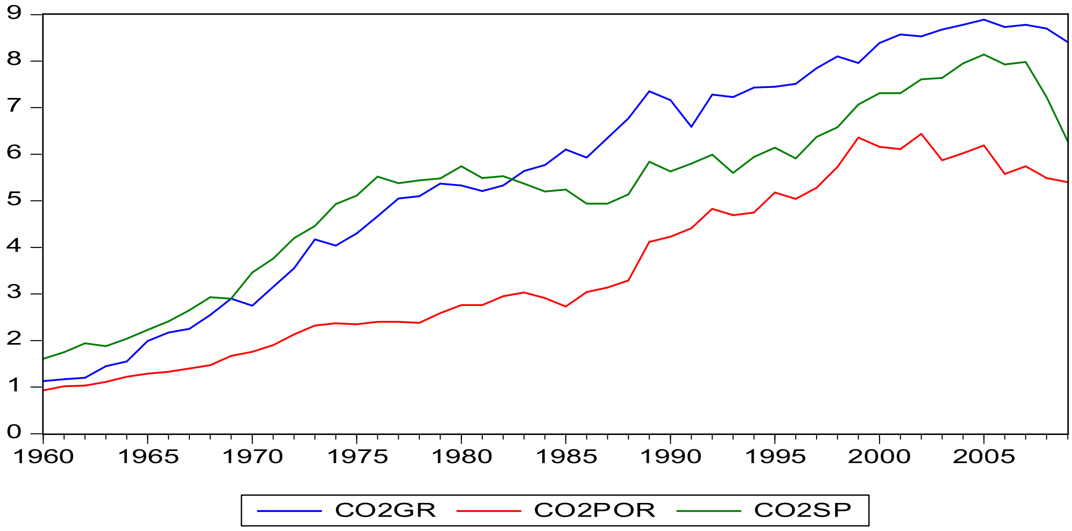
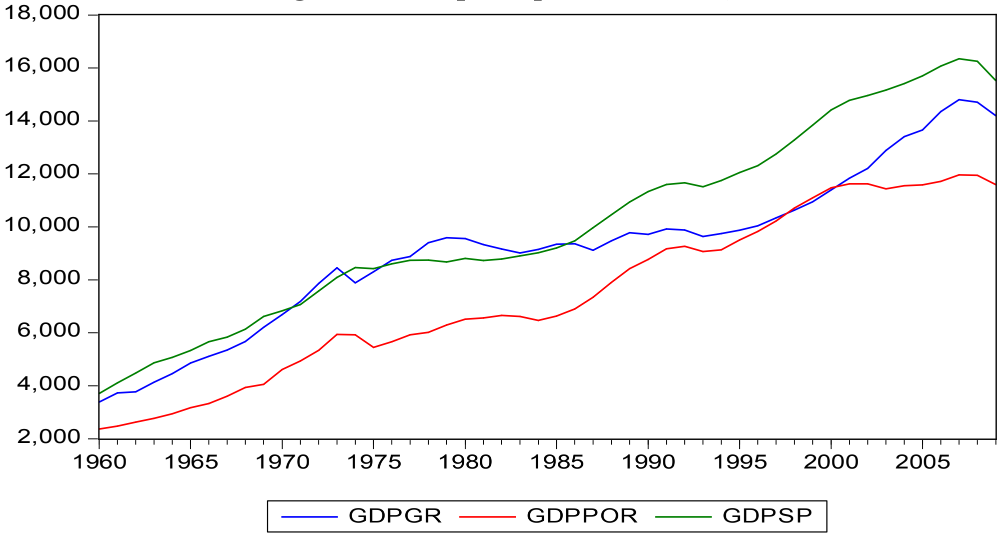


Figure 3. GDP per capita (1960-2009)



The rest of the paper is organized as follows. The next section presents a brief literature review on causality link between energy consumption, economic growth and CO2 emissions. Section 3 describes the data and methodology. Section 4 highlights the empirical results and the last one concludes and states the policy implications of the results.

2. Literature Review

The relationship between energy consumption and economic growth as well as economic growth and environmental pollution has been the main issue of intensive research during the last two decades. In previous years some studies, using panel data, reveal different results which depend upon the countries and the period held in the analysis, as well as the econometric techniques used (see Ozturk, 2010).

Maddison and Rehdanz (2008) examine the causal relationship between GDP and carbon emissions in a panel data for 134 countries for the period from 1990 until 2005 inserting the meaning of the homogeneous non-causality in heterogeneous data. The results of their paper show that there is no causal relationship between CO2 emissions and GDP in North America, Asia and Oceania.

Costantini and Martini (2010) using a vector error correction model examine the causal relationship between energy consumption and economic growth in a sample of developed and developing countries during the period 1960 - 2005. Their results show differences, as far as the direction of causality is concerned, which have been discovered in samples of the examined countries, particularly in specific sectors they analyze.

Apergis and Payne (2010) follow an inverted U-shape pattern associated with the Kuznets Curve and using an error correction model they examine the causal relationship between energy consumption, carbon dioxide emissions and production for eleven countries of the Commonwealth of independent states during the period 1992–2004. Their results show a bidirectional causal relationship between energy consumption and CO2 emissions in the long run and a unidirectional causal relationship between energy consumption and production towards carbon dioxide emissions, in the short run.

Lean and Smyth (2010) using the environmental Kuznets curve, examine the causal relationship between carbon dioxide emissions, electricity consumption and economic growth for five ASEAN countries during the period 1980 – 2006. The long run causal estimations showed that there is a unidirectional relationship running from electricity consumption and CO2 emissions towards economic growth. The short run causal estimations showed again unidirectional relationship running from CO2 emissions towards electricity energy.

Acaravci and Ozturk (2010) examine the causal relationship between carbon dioxide emissions, energy consumption, and economic growth by using autoregressive distributed lag bounds testing approach of cointegration for 19 European countries. The bounds *F*-test for cointegration test yields evidence of a long-run relationship between carbon emissions per capita, energy consumption per capita, real gross domestic product (GDP) per capita and the square of per capita real GDP only for Denmark, Germany, Greece, Iceland, Italy, Portugal and Switzerland. Their results support that the validity of environmental Kuznets curve (EKC) hypothesis in Denmark and Italy.

Li et al. (2011) examine the causal relationship between CO2 emissions, energy consumption and economic growth for 30 provinces of mainland China from 1985 until 2007. The results of their paper showed that there is unidirectional causal relationship between GDP and energy consumption running from GDP to energy consumption as well as a unidirectional causal relationship running from GDP to CO2 emissions. Finally, the long run positive cointegrated relationship of their paper showed that if per capita GDP increases by 1%, energy consumption will increase by 0.50% approximately while CO2 emissions will increase by 0.43%.

Farhani and Rejeb (2012) examine the causal relationship between CO2 emissions, energy consumption and economic growth for 15 MENA countries covering the period from 1973 -2008. In order to deal with the heterogeneity of these countries, the estimation of long run relationship is conducted with FMOLS and DOLS. The results of their paper showed that in the short run there is no causal link between economic growth and energy consumption as well as between CO2 emissions and energy consumption. However, in the long run, there is a unidirectional causality running from economic growth and CO2 emissions to energy consumption.

Aslan et al. (2013) using heterogeneous panel data examine the relationship between energy consumption and economic growth for 47 US States over the period 1997-2009. The results of their paper showed that in all examined States there is a bidirectional causal relationship between energy consumption and economic growth**.** In general, the empirical literature suggests that the causality relations depend on econometrics methods and the period that studies were carried out. The results can be unidirectional causality, bidirectional causality or no causality relation. In any case, the results seem to indicate a positive relation among energy consumption and CO2 emissions, as well as economic growth and energy consumption.

Table 1. Causality relations among EC, CO2 emissions and GDP for a group of countries using panel data

Authors	Period	Country	Results
Maddison and Rehdanz (2008)	1990 -2005	134 countries	North America, Asia and Oceania ($CO_2 \neq$ GDP)
Costantini and Martini (2010)	1960 - 2005	developed and developing countries	Differences in the causality direction have been detected in subsamples of countries, particularly in the specific sector analysis
Apergis and Payne (2010)	1992 - 2004	eleven countries of the Commonwealth of Independent States	$EC \Leftrightarrow CO2$ EC $\Rightarrow$ CO2 GDP $\Rightarrow$ CO2
Lean and Smyth (2010)	1980 - 2006	five ASEAN countries	EC $\Rightarrow$ GDP CO2 $\Rightarrow$ GDP CO2 $\Rightarrow$ EC
Li et al. (2011)	1985 - 2007	30 provinces in mainland China	GDP $\Rightarrow$ EC GDP $\Rightarrow$ CO2
Farhani and Rejeb (2012)	1973 - 2008	15 MENA countries	EC $\neq$ GDP CO2 $\neq$ EC GDP $\Rightarrow$ EC CO2 $\Rightarrow$ EC
Aslan et al. (2013)	1997 - 2009	47 US states	EC $\Leftrightarrow$ GDP

3. Data and Methodology

After obtaining the descriptive statistics of the variables, we continue with the following analyses for the causal relationship between energy consumption, CO2 emissions and economic growth (GDP): the panel unit root analysis, the panel cointegration analysis, the estimation of long run relationship using FMOLS and DOLS methods and finally the estimation of causal relationship through error correction model.

3.1 Data

The variables used in this study are energy consumption (EC) measured in kg of oil equivalent per capita, GDP per capita measured in constant prices of year 2000 in US$ and CO2 emissions measured in metric tons per capita. The data set is a balanced panel of three member states of E.U over the annual period 1960-2009. The three countries of European Union included in the sample are: Greece (GR), Spain (S) and Portugal (POR). All variables come from the World Development Indicators (WDI, 2010). In order to reduce the heterogeneity of the data among the examined countries, we change the variables in natural logarithms. The descriptive statistics of different variables for three E.U countries are given on Table 2.

3.2 Econometric methodology

After descriptive statistics for the three examined variables of the three countries of EU, our paper involves four objectives:

- The first is to examine the stationarity of the variable using panel unit root tests.
- The second is to examine the long run relationship using cointegration analysis among variables used on panel data.

- The third is to estimate the long run relationship with panel Fully Modified Ordinary Least Square (FMOLS) and Dynamic Ordinary Least Square (DOLS) methods.
- The fourth aim is to estimate a dynamic panel vector error correction model (VECM) in order to provide us with the Granger causal relationships

Table 2. Descriptive statistics

	LEC	LCO2	LGDP
Mean	7.2523	1.4178	9.0058
Median	7.4434	1.6467	9.1099
Maximum	8.0922	2.1849	9.7020
Minimum	5.6666	-0.0725	7.7700
Std. Dev.	0.6260	0.5896	0.4392
Skewness	-0.7864	-0.7806	-0.7569
Kurtosis	2.5810	2.5579	3.0525
Jarque-Bera	16.5615	16.4582	14.3412
Probability	0.0002	0.0002	0.0007
Observations	150	150	150
Cross sections	3	3	3

4. Empirical Results

4.1 Panel unit root analysis

We begin by testing the stationarity of three variables Energy Consumption (EC), CO2 emissions and GDP. The recent literature proposes several methods for unit root tests in panel data. Since these methods may give different results, we selected Levin, Lin and Chu (2002) t* (LLC), Breitung (2000) t-stat, Im, Perasan and Shin (2003) W-test (IPS), ADF Fisher Chi-square test (ADF-Fisher), PP Fisher Chi-Square test (PP-Fisher), Maddala and Wu (1999) and Hadri (2000) to perform panel data unit root tests. In all these tests except Hadri (2000), the null hypothesis is that the variable contains a unit root (i.e., it is not stationary). The results of level and first difference unit root tests for the three variables are provided on Table 3.

Table 3. Panel unit root test results

Method	LEC	LCO2	LGDP
		LLC-t*	
Level	-0.06260 (0.470)	-0.3294 (0.370)	-0.5017 (0.307)
First difference	-1.22556 (0.110)	-3.162 (0.000)***	0.1288 (0.551)
		Breitung-t-stat	
Level	4.63591 (1.000)	4.5665 (1.000)	3.3776 (0.999)
First difference	-0.34594 (0.364)	-0.2498 (0.401)	-0.7503 (0.226)
		IPS-W-stat	
Level	2.62032 (0.995)	2.0517 (0.979)	0.5278 (0.701)
First difference	-3.4601 (0.000)***	-5.479 (0.000)***	-2.828 (0.002)***
		ADF-Fisher X^2	
Level	1.16910 (0.978)	1.6107 (0.951)	3.0365 (0.804)
First difference	23.503 (0.000)***	39.626 (0.000)***	18.406 (0.005)***
		PP-Fisher X^2	
Level	1.23136 (0.975)	1.7402 (0.942)	8.1052 (0.230)
First difference	58.654 (0.000) ***	85.395 (0.000)***	31.868 (0.000)***
		Hadri – Z stat	
Level	5.7800 (0.000)***	5.662 (0.000)***	4.348 (0.000)***
First difference	1.33270 (0.091)*	0.9054 (0.182)	2.664 (0.003)***

Notes: The null hypothesis of these tests is that the panel series has a unit root (nonstationary series) except for the Hadri test which has no unit root in panel series. The numbers in parentheses denote p values. ***, **, * denotes rejection of null hypothesis at the 1%, 5% and 10% level of significance, respectively. Probabilities for Fisher-type tests were computed by using an asymptotic X^2 distribution. All other tests assume asymptotic normality. The lag length is selected using the Modified Schwarz Information Criteria. All variables are in natural logarithms.

As can be seen from Table 3 all series are non-stationary in the level of variables while they become stationary at the 1% significance level of the first difference. Therefore, we can say that all variables are I(1).

4.2 Panel cointegration analysis

Since the order of stationarity has been defined, our next step is to apply panel cointegration methodology. Three types of panel cointegration tests were conducted. The first test developed by Pedroni (1999, 2004) proposed seven panel cointegration statistics under null hypothesis H_0: p_i=0. The seven tests are based on the absence of cointegration. The second test conducted is the residual based panel cointegration test developed by Kao (1999) proposed to estimate the homogeneous cointegrating relationship. The third panel cointegration test we apply is the Johansen (1988) - type panel cointegration test developed by Maddala and Wu (1999). This test is based on the cointegration trace and maximum eigenvalue tests by Johansen (1991). The cointegration panel model of energy consumption for the heterogeneity of the examined countries is given as follows:

$$LNEC_{it} = \beta_{0it} + \beta_{1it} LNCO2_{it} + \beta_{2it} LNGDP_{it} + u_{it} \qquad i = 1,\ldots,N \text{ and } t = 1,\ldots T \qquad (1)$$

The above equation describes a cointegrated panel regression that allows for heterogeneity in the pane slope coefficients and deterministic trends. (Pedroni, 1999, 2004). Finally, β_o, β_1, β_2 are the parameters of the model to be estimated, and u_{it} are the residuals.

Table 4. Panel cointegration tests

Pedroni residual cointegration tests (LNEC as dependent variable)		
	Test statistic	**Probability**
Within-dimension		
Panel v-Statistic	2.421503***	0.0077
Panel rho-Statistic	-2.112507**	0.0173
Panel PP-Statistic	-2.786999***	0.0027
Panel ADF-Statistic	-0.689870	0.2451
Between-dimension		
Group rho-Statistic	-1.162749	0.1225
Group PP-Statistic	-2.278228***	0.0114
Group ADF-Statistic	-0.680050	0.2482
Kao residual cointegration tests (LNEC as dependent variable)		
	t- statistic	**Probability**
ADF	-4.343710***	0.0000
Johansen–Fisher panel cointegration tests		
	Fisher statistic (from trace test)	**Probability**
None	15.10**	0.0195
At most 1	4.801	0.5696
At most 2	1.648	0.9490

Notes: The null hypothesis is that the variables are not cointegrated. Under the null tests, all variables are distributed normal, N(0, 1), ***, ** and * significant at the 1%, 5% and 10% levels, respectively. Fisher's test (1932) applied regardless of the dependent variable. Asymptotic p-values are computed using X^2 distribution.

The results from table 4 show that all three methods of cointegration test support the presence of a cointegrated relationship between the three variables at the 1% significant level, respectively. In other words, we conclude that there is a long run equilibrium relationship among examined variables meaning that energy consumption, economic growth (GDP) and CO2 emissions are moving together in the long run. As the existence of the cointegrating relationship was supported, we estimated the energy consumption function using the OLS, FMOLS and FMOLS methods developed by Pedroni (2001).

4.3 Panel OLS, FMOLS and DOLS estimates

Given that our variables are cointegrated, the next step is to estimate the long-run equilibrium relationship. The OLS estimator is a biased and inconsistent estimator when applied to cointegrated panel. For this reason, Pedroni suggested a fully modified OLS estimator, the FMOLS which becomes a dynamic DOLS and gives for the between-dimension "group mean", the estimators of DOLS and FMOLS methods. These estimators allow us for a larger flexibility in the presence of heterogeneity in the examined cointegrated vectors (Pedroni 1999, 2000, 2001, 2004). Furthermore, the above methods allow on the null hypothesis to test if there is a strong relationship between energy consumption, CO2 emissions and economic growth for the examined countries

The test statistics derived from the between-dimension estimators are constructed to test the null hypothesis $H_0 : \beta_i = \beta_0$ for all i against the alternative $H_1 : \beta_i \neq \beta_0$, so that the values for β_i are not constrained to be the same under the alternative hypothesis.

Considering the following co-integrated system for a panel of i =1,…, N members we get

$$y_{it} = \alpha_i + \beta x_{it} + u_{it} \quad \text{for i =1,…,N and t = 1,…T} \tag{2}$$

$$x_{it} = x_{it-1} + e_{it} \tag{3}$$

where y_{it} is a matrix (1×1), α_i is individual fixed effect, β is a vector of slopes ($k\times1$) dimension, x_{it}, is a vector ($k\times1$) dimension. $Z_{it} = (y_{it}, x_{it})' \to I(1)$, $\Xi_{it} = (u_{it}, e_{it})' \to I(0)$.

In this paper, we consider three estimators: OLS, Fully Modified OLS (FMOLS), and dynamic OLS (DOLS) to empirically examine energy consumption in three countries of Southern Europe. The Fully Modified OLS (FMOLS) and Dynamic OLS (DOLS) methodologies are proposed by Kao and Chiang (2000) to estimate the long-run cointegration vector, for non-stationary panels.

The OLS estimator is given from the following type:

$$\hat{\beta}_{OLS} = \left[\sum_{i=1}^{N}\sum_{t=1}^{T}(x_{it} - \bar{x}_i)(x_{it} - \bar{x}_i)'\right]^{-1}\left[\sum_{i=1}^{N}\sum_{t=1}^{T}(x_{it} - \bar{x}_i)(y_{it} - \bar{y}_i)\right] \tag{4}$$

where $\bar{x}_i = \dfrac{\sum_{t=1}^{T}(x_{it})}{T}$ and $\bar{y}_i = \dfrac{\sum_{t=1}^{T}(y_{it})}{T}$

Examining the limited distribution of the FMOLS and DOLS estimators in co-integrated regressions, Kao and Chiang (2000) show that they are asymptotically normal. The FMOLS estimator is constructed by making corrections for endogeneity and serial correlation to the OLS estimator and is defined as:

$$\hat{\beta}_{FM} = \left[\sum_{i=1}^{N}\sum_{t=1}^{T}(x_{it} - \bar{x}_i)(x_{it} - \bar{x}_i)'\right]^{-1}\left[\sum_{i=1}^{N}\left(\sum_{t=1}^{T}(x_{it} - \bar{x}_i)\hat{y}_{it}^{*} + T\hat{\Delta}_{EM}^{*}\right)\right] \tag{5}$$

$\hat{y}_{it}^{*}$ is the transformed variable of y_{it} to achieve the endogeneity correction, where $\left(\hat{y}_{it}^{*} = y_{it} - \hat{\Omega}_{EM}\hat{\Omega}_{E}^{-1}\Delta x_{it}\right)$, and $\hat{\Delta}_{EM}^{*}$ is the serial correlation correction term, where $\left(\hat{\Delta}_{EM}^{*} = \hat{\Delta}_{EM} - \hat{\Delta}_{E}\hat{\Omega}_{E}^{-1}\hat{\Omega}_{EM}\right)$

The serial correlation and the endogeneity can also be corrected by using DOLS estimator. The DOLS is an extension of Stock and Watson's (1993) estimator.

The dynamic OLS estimator is obtained from the following equation:

$$y_{it} = \alpha_i + \beta x_{it} + \sum_{j=q_1}^{j=q_2} c_{ij}\Delta x_{i,t-j} + V_{it} \tag{6}$$

c_{ij} is the coefficient of a lead or lag of first differenced explanatory variables.

The estimated coefficient of DOLS is given from the following equation:

$$\hat{\beta}_{DOLS} = \left[\sum_{i=1}^{N} \sum_{i=1}^{T} q_{it} q_{it}^{/} \right]^{-1} \left[\sum_{i=1}^{N} \sum_{i=1}^{T} q_{it} \hat{y}_{it}^{*} \right] \quad (7)$$

Where q_{ij} is $2(q+1)\times 1$ vector of regressors. $q_{ij} = \lfloor x_{it} - \overline{x}_i \Delta x_{i,t-q},...,\Delta x_{i,t+q} \rfloor$.

The test results from OLS, FMOLS and DOLS estimations are reported on Table 5.

The results from table 5 show that both the individual tests and the panel tests reject the null hypothesis of strong relation which runs from CO2 emissions and economic growth to energy consumption. Starting from the relationship which runs from CO2 emissions to energy consumption, among the individual country tests and also from all countries panel data, we can see that the null hypothesis is rejected at 1% level for the OLS method. We get the same results from all countries and for the FMOLS and DOLS methods at 1% level of significance.

Table 5. OLS, FMOLS DOLS estimates for three countries (LNEC as dependent variable)

	LNCO2			LNGDP		
Country	**OLS**	**FMOLS**	**DOLS**	**OLS**	**FMOLS**	**DOLS**
Greece	0.838***	0.884***	0.906***	0.373***	0.292***	0.284**
Spain	0.544***	0.580***	0.575***	0.736***	0.711***	0.738***
Portugal	0.946***	0.972***	0.925***	0.169*	0.142	0.214*
Panel	0.462***	0.771***	0.729***	0.795***	0.440***	0.512***

Notes: Asymptotic distribution of t-statistic is standard normal as T and N go to infinity.
***, ** and *Significant at the 1%, 5% and 10% levels, respectively.

Also, there is a positive relationship between economic growth and energy consumption at 1% level of significance for Spain and Greece whereas for Portugal the level of significance is only 10% and only for OLS and DOLS.

For the panel tests, it is observed that there is a strong positive relationship which runs from economic growth to energy consumption and from CO2 emissions to energy consumption in 1% level of significance.

4.4 Panel causality analysis

In order to investigate the short and long-run dynamic relationships on panel data among the variables of energy consumption, CO2 emissions and economic growth we adopt the two steps Engle and Granger (1987) method. Engle and Granger (1987) support that if two time series X and Y are integrated I(1) and cointegrated then there would be at least one causal relationship in one direction. However, the direction of causality can be detected through the Vector Error Correction model (VECM) of long-run cointegrating vectors. Thus, on the first step we find out the long run equilibrium relationship from Equation (1) and save the residuals corresponding to the deviation from equilibrium point. The second step estimates the parameters related to the short-run adjustment. The equations that arise for panel Granger causality testing are the following:

$$\Delta LNEC_{i,t} = \alpha_{1,i} + \sum_{k=1}^{m} \alpha_{1,1,i,k} \Delta LNEC_{i,t,k} + \sum_{k=1}^{m} \alpha_{1,2,i,k} \Delta LNCO2_{i,t-k} + \sum_{k=1}^{m} \alpha_{1,3,i,k} \Delta LNGDP_{i,t-k} + \quad (8)$$

$$+ \lambda_{1,t} ECT_{i,t-1} + u_{1,i,t}$$

$$\Delta LNCO2_{i,t} = \alpha_{2,i} + \sum_{k=1}^{m} \alpha_{2,1,i,k} \Delta LNEC_{i,t,k} + \sum_{k=1}^{m} \alpha_{2,2,i,k} \Delta LNCO2_{i,t-k} + \sum_{k=1}^{m} \alpha_{2,3,i,k} \Delta LNGDP_{i,t-k} + \quad (9)$$

$$+ \lambda_{2,t} ECT_{i,t-1} + u_{2,i,t}$$

$$\Delta LNGDP_{i,t} = \alpha_{3,i} + \sum_{k=1}^{m} \alpha_{3,1,i,k} \Delta LNEC_{i,t,k} + \sum_{k=1}^{m} \alpha_{3,2,i,k} \Delta LNCO2_{i,t-k} + \sum_{k=1}^{m} \alpha_{3,3,i,k} \Delta LNGDP_{i,t-k} + \quad (10)$$

$$+ \lambda_{3,t} ECT_{i,t-1} + u_{3,i,t}$$

where Δ denotes first differences, k=1,…,m is the optimal lag length determined by the Schwarz Information Criterion, $\alpha_{j,i,t}(j=1,2,3)$ represents the fixed country effect,

$ECT_{i,t-1}$ is the estimated lagged error correction term derived from the long-run cointegrating relationship of Equation (1), $\lambda_{j,i,}(j=1,2,3)$ is the adjustment coefficient and $u_{j,i,t}$ is the disturbance term assumed to be uncorrelated with zero means.

The results on panel data for short and long-run dynamic Granger causality relationships are presented on Table 6.

Table 6. Panel causality tests.

Dependent variable	Sources of causation (independent variables) F-statistic			t-test
	Short-run			Long-run
	ΔLEC	ΔCO2	ΔGDP	ECT
ΔLEC		0.460***	0.590***	-0.085***
ΔCO2	0.086***		0.206*	0.027
ΔGDP	0.473***	0.098*		0.054**

Notes: Δ denotes first difference, ***, ** and *Significant at the 1%, 5% and 10% levels, respectively. Short-run causality is determined by the statistical significance of the partial F-statistics associated with the right hand side variables. Long-run causality is revealed by the statistical significance of the respective error correction terms using a t-test

From the results of table 6 we can see that:

- There is a short run causal relationship from LNGDP and LNCO2 to LNEC. We can point out that according to this result; energy consumption is affected by CO2 emissions and economic growth.
- There is a short run causal relationship from LNEC and LNGDP to LNCO2. This means that CO2 emissions are affected from energy consumption and economic growth.
- Also, there is a short run causal relationship from LNEC and LNCO2 to LNGDP showing that economic growth is affected by CO2 emissions and energy consumption.
- Furthermore, the results on table 4 show that there is a bidirectional causal relationship on three examined variables in the short run. This means that an increase on energy consumption can lead to an increase on economic growth and that policies applying for the reduction of energy consumption can decelerate both economic growth and CO2 emissions.
- In the long run, the estimated coefficients of ECT in equations of energy consumption and economic growth are significant at 1% and 5% respectively, implying that energy consumption and economic growth could play an important adjustment role as the system departs from the long-run equilibrium.

5. Conclusion and Policy Implications

The principal aim of this paper was to find out the causal relationships among energy consumption, economic growth and carbon emissions in three countries of Southern Europe, member states of EU, during the period 1960 to 2009. This study employed a panel unit root test on the examined variables, three panel cointegration methods and dynamic panel causality test with error correction model. The panel cointegration test reveal the existence of a panel long-run equilibrium relationship between energy consumption, the CO2 emissions and economic growth meaning that these three variables, for all three examined countries, move together in the long run.

We then apply the estimation methods OLS, FMOLS and DOLS in order to test is there is strong relationship between energy consumption, CO2 emissions and economic growth for the examined countries. The estimation results show that for all countries of Southern Europe, and applying all methods, there is a positive relationship between CO2 emissions and energy consumption in 1% level of significance. Also, there is a positive relationship between economic growth and energy consumption in 1% level of significance for Greece and Spain, whereas for Portugal the level of significance is 10% for OLS and DOLS methods. This means that a high level of economic growth leads to high level of energy demand for Greece and Spain, explaining the strong relationship between energy consumption and economic growth, while this is not the case for Portugal. When panel tests were applied, the observed strong relationship running from economic growth to energy consumption and from CO2 emissions to energy consumption was overwhelmingly rejected.

In order to test the causality of panel data we created the error correction model (ECM) followed by the two steps of Engle and Granger in order to investigate the short and long-run dynamic relationships. The empirical results suggest that in the short run there is a bidirectional causal relationship on the three variables under examination. This implies that in the short run an increase in energy consumption will lead to an increase on CO2 emissions and subsequently to an increase in economic growth. Therefore, policies for the reduction of energy consumption will decelerate not only the economic growth but also the CO2 emissions. In the long run, the estimated coefficients on error correction term on equations of energy consumption and economic growth are statistically significant at the 1% and 5% level of significance respectively. This means that energy consumption and economic growth could play an important role when the system withdraws from the long run equilibrium base. The policymakers should then take into consideration the degree of economic growth in each country when energy consumption policy is formulated.

The empirical results of this study will help the countries of Southern Europe to trace out an energy policy for a quicker economic growth and get out from a recession. The examination of the causal relationship between energy consumption and economic growth, given that the right use of energy is regarded as the best tool for the sustainable growth, has major policy implications. When energy consumption leads growth positively this means that the use of energy helps the production procedure. Thus, the benefit of these countries is greater than the cost of energy use. On the contrary, if an increase in economic growth brings about an increase in energy consumption, then countries should turn in more profitable technologies reinforcing the domestic production mainly through the assistance of financial sector.

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