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Energy Consumption and Economic Growth Nexus: Evidence from Developed Countries in Europe

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ABSTRACT: This paper analyzes the relationship between renewable and non-renewable energy consumption and economic growth for a panel of fifteen European Union countries over the period 1990-2011 within a multivariate framework. The heterogeneous panel cointegration tests present a long-run equilibrium relationship between real GDP, renewable and non-renewable energy consumption, greenhouse gas emissions and research and development. The Granger-causality results demonstrate unidirectional causality between non-renewable energy consumption and economic growth.

Keywords: renewable energy consumption; non-renewable energy consumption; growth
JEL Classifications: C23; O11; O13

1. Introduction

For all countries whether developed or developing, energy is an essential production factor like capital and labor. Moreover, energy consumption is one of the basic indicators of economic development and growth. As Halıcıoglu (2009) stressed economic development and output may be jointly determined because economic growth is closely related to energy consumption because higher economic development requires more energy consumption. Likewise, "*more efficient energy use*" needs a higher level of economic development. Therefore, the direction of causality may not be determined a priori.

The purpose of this paper is to investigate European Union (EU) member 15 countries' the long-run and casual relationships between renewable non-renewable energy consumption and economic growth. EU-15 includes: Austria, Belgium, Denmark, Germany, Ireland, Greece, Spain, France, Italy, Luxemburg, Netherlands, Portugal, Finland, Sweden and United Kingdom. The reason for choosing for these countries is that, these countries share is nearly more than %80 in gross inland consumption of primary energy over the period 2000-2010 (Eurostat) in EU and it can be said that these countries' economic background and characteristics are roughly similar.

Moreover *EU is frontrunner in the world in point of renewable energy usage and aims to* decrease greenhouse gas emissions and *mitigates the* climate change. Accordingly in 2007, the European Commission developed a proposal for the first EU-wide energy strategy and the Commission adopted the famous 20/20/20 target: (i) 20% savings in energy consumption compared to projections, (ii) a share 20% share of the renewable energy mix by renewable energy sources, (iii) a 20% decrease in greenhouse gas emissions compared to 1990 levels by 2020 (GEF, 2013). So, it will be useful to analyze these countries whether their policies answer the purpose or not.

The paper's method is a multivariate panel framework and this method makes it possible to simultaneously assess the performance of EU-15 countries in terms of economic growth, renewable and non-renewable energy consumption and greenhouse gas emissions. Including greenhouse gas emissions and energy technology research and development indicators variables in panel framework, we enlarge the scope of the analysis. Using a multivariate panel framework we aim to overcome the problem about omission of relevant variables as mentioned by Stern (1993).

Moreover according to the results, it would be possible to determine which type of energy consumption is more important for economic growth in 1990-2011 time periods. 1990-2011 periods is chosen because the data is available for this time period. The paper is organized as follows: Next section is devoted to the theoretical background. Section 3 is literature review and Section 4 presents data, methodology and results. Finally Section 5 concludes.

2. Theoretical Background

Mainstream growth models (neoclassical and endogenous growth models) analyze the effects of primary production factors like capital and labor on economic growth. Energy and the type of the energy which is used in production process are frequently ignored or most probably are accepted as an intermediate input. By this way an implicit role can be given to energy as an input in the growth process. As Stern (1998) emphasizes the basic model of economic growth or in other words neoclassical model by Solow (1956) does not include resources at all. According to this theory, the only cause of continuing economic growth is technological progress. But technological progress is assumed exogenously happened; it falls as "manna from heaven". Later on, endogenous growth models attempt to explain technological progress within in the growth model as the outcome of decisions taken by firms and individuals (Stern, 1998).

In the course of time as countries have developed economies move to an industry intensive structure from an agriculture intensive structure so that energy takes an explicit role in economic growth. Moreover with this development process environmental pollution, threat of global warming and climate change have become vital problems, so economists/researchers stressed the role and type of energy in the growth process. All of these factors mentioned above lead an excess interest on energy consumption and economic growth nexus.

3. Literature Review

In Kraft and Kraft's (1978) seminal paper, it is emphasized that "according to current view, there is a constant and unchanging relationship between gross energy consumption and GNP and the direction of causality runs from energy to GNP as well as the other way around". According their papers' findings the causality is unidirectional only running from GNP to energy for the postwar period, and there is no causality from energy to GNP (Kraft, 1978:401). There is an extensive number of empirical works about economic and energy consumption but their results are contradictory.

In Table 1, there is a chronological list of selected papers in the empirical literature on energy consumption and economic growth nexus. In this literature survey there are both country-specific and multi-country studies and also the papers which decompose the energy type as renewable and non-renewable.[1]

The literature on the casual relationship between energy consumption and economic growth rests upon four testable hypotheses: growth, conservation, feedback, and neutrality. The premise behind the growth hypothesis energy consumption plays a vital role in economic growth directly and/or as a complement to capital and labor. The conservation hypothesis postulates that energy consumption is determined by economic growth. The feedback hypothesis depends upon the interdependent relationship between energy consumption and economic growth. The neutrality hypothesis rests on the assumption that energy consumption has a relatively minor role in the economic growth process (Apergis and Payne, 2012).

This large number of papers, which analyze the empirical relationship between energy use and economic growth, can be classified according to different criteria. For example; Mehrara (2007) classified the papers into four generations based on the methodology used First generation studies are based on a traditional VAR methodology and Granger causality testing. Second and third generation

[1] For a detailed literature survey see the study of Ozturk (2010).

studies apply unit root and cointegration tests moreover third generation studies use multivariate estimators. Fourth generation studies use panel –based unit root and cointegration testing procedures. As it is seen in time the econometric techniques used have become more and more sophisticated.

Tugcu et al. (2012) classify this literature according to the consumed energy type. The first strand includes studies which investigate the relationship between (dis)aggregate energy consumption and economic growth without making any qualitative discrimination. The papers in the second strand analyze the relationship between renewable energy consumption and economic growth. Finally, the new trend in energy economics literature is to decompose the effects of renewable and non-renewable energy consumption on economic growth (Tugcu et al. 2012: 1944). This new trend comes in sight since there is a substitution among energy forms and this phenomenon will be increasingly continue and the renewable energy is expected to take the lead in the race with fossil fuels. The reason of this phenomenon is; all fossil fuels have an exhaustible character and the earth's reserves of nonrenewable energy are assumed to run out sooner or later but the renewable energy potential is huge and it represents one of the safest ways of handling the increasing energy demand, without affecting the balance of an economic development (Pirlogea and Cicea, 2012).

Table 1. Summary of Literature Review on Energy Consumption and Economic Growth Nexus

Authors	Country	Period	Methodology	Result
Kraft & Kraft (1978)	USA	1947-1974	Sims technique	GDP→EC
Stern (1993)	USA	1947-1990	Multivariate VAR model	GDP→EC EC→GDP[2]
Chang et.al (2001)	Taiwan	1982:1-1997:11	Cointegration & vector error correction	EC→GDP
Soytaş & Sari (2003)	Top 10 emerging markets & G-7 countries	1950-1992	Cointegration & vector error correction	GDP→EC (Italy & Korea) EC→GDP(Turkey, France, Germany, Japan)
Chen et al. (2007)	10 Asian countries	1971-2001	Panel cointegration, ECM & Panel causality tests	EL↔GDP (for all countries) EL→GDP(Hong Kong) GDP→EL (India, Singapore, Malaysia, Philippines) GDP----EL (Indonesia, Korea, Taiwan, Thailand, China)
Mehrara (2007)	11 oil exporting countries	1971-2002	Panel cointegration	GDP → EC
Huang et al. (2008)	82 developing & developed countries	1972-1992	Panel VAR, GMM	GDP----EC (low income countries) GDP→EC (middle and high income countries)
Narayan & Smyth (2009)	6 middle eastern oil exporting countries	1974-2002	Panel cointegration & Panel causality tests	EL↔GDP
Apergis et al. (2010)	19 developing & developed countries	1984-2007	Panel error correction mode	Renewable EC↔GDP
Ozturk et.al (2010)	51 low & middle Income countries	1971-2005	Panel cointegration & Panel causality tests	GDP→EC (low income countries) EC↔GDP (middle income countries)
Yalta (2010)	Turkey	1950-2006	Maximum entropy bootstrap	GDP----EC (both short and long run)
Kaplan et.al (2011)	Turkey	1971-2006	Vector error correction model	EC↔GDP (in the long run)
Lau et al. (2011)	17 Asian countries	1980-2006	anel cointegration & Panel causality tests	EC→GDP(in the short run) GDP → EC (in the long run)

[2] Stern (1993) replaced gross energy use with an index of final energy use weighted for the changing fuel composition of the energy input and the direction of the relationship changed.

Li et al. (2011)	China	1985-2007	Dynamic OLS	EC→GDP per capita (in the long run)
Menegaki (2011)	27 European countries	1997-2007	Panel causality tests& one-way random effect model	GDP----EC
Apergis & Payne (2012)	80 countries	1990-2007	Panel cointegration & Panel error correction model	EC↔GDP (both in the short and in the long run)
Tugcu et al. (2012)	G-7 countries	1980-2007	ARDL	EC↔GDP (both for renewable and non-renewable)
Kazar & Kazar (2013)	154 countries	1980-2010 2005-2010	Granger causality	ED→REP(in the long run) ED↔REP(in the short run)
Abalaba & Dada (2013)	Nigeria	1971-2010	Error correction Model	EC→GDP(in the short run) GDP----EC (in the long run)
Menegaki &Ozturk (2013)	26 European countires	1975-2009	Dynamic error correction model	Fossil EC→GDP(in the long run)
Dogan (2014)	Benin, Congo, Kenya, Zimbabwe	1971-2011	Granger causality	EC→GDP(Kenya) GDP---EC(Benin,Congo, Zimbabwe)

Note:EC→GDP means that the causality runs from energy consumption to economic growth.
GDP→EC means that the causality runs from economic growth to energy consumption.
EC↔GDP means that bi-directional causality exists between energy consumption and economic growth
GDP----EC means that no causality exists between energy consumption and economic growth
ED means economic development, REP means renewable energy production
EL means electric consumption

As mentioned above papers in the literature use different sample, econometric methodologies and time period. In these studies either a group of countries or a specific country is chosen and also the variables, which are included in the estimation equations, have become notably diversified in time. So it can be said that today energy consumption and economic growth nexus is investigated with different and extensive variable scala. Firstly Stern (1993) uses a multivariate framework. Stern (1993) emphasizes that multivariate framework is more advantageous than bivariate framework because multivariate framework can help avoid spurious correlations and can aid in testing the general validity of the causation test. In this paper the causal relationship between energy consumption, capital, labor and GDP is investigated on USA for 1947-1990 time periods. According to the results changes in gross energy use do not cause economic growth, but economic growth causes changes in gross energy use. After this result Stern (1993) replaced gross energy use with an index of final energy use weighted for the changing fuel composition of the energy input and obtained the result that final use adjusted for changing fuel composition does Granger cause GDP.

Narayan and Smith (2009) examine the relationship between electricity consumption, GDP and exports for a group of Middle Eastern countries for 1974-2002 time period. According to paper's result there are feedback effects between these variables.

Apergis et al. (2010) examine the causal relationship between CO_2 emissions, nuclear energy consumption, renewable energy consumption and economic growth for 19 developed and developing countries for 1984-2007 time period. According to the results there is bidirectional causality between renewable energy consumption and economic growth so the feedback hypothesis is valid and also nuclear energy has an important role in reducing CO_2 emissions.

Apergis and Payne (2010) examine renewable energy consumption and economic growth relationship for 20 OECD countries for 1985-2005 time period. There is a multivariate framework and the other variables that are included real gross fixed capital formation and labor force.

Menegaki (2010) examines the casual relationship between economic growth and renewable energy for 27 European countries in a multivariate panel framework for the 1997-2007 time period. In this multivariate panel framework additional variables are; greenhouse gas emissions and employment. The results indicate the evidence of the neutrality hypothesis.

Apergis and Payne (2012) examine the relationship between renewable and non-renewable energy consumption, real gross fixed capital formation, the labor force and real GDP for 80 countries. The results reveal that the feedback hypothesis is valid in other words there is bidirectional causality between renewable and non-renewable energy consumption and economic growth.

Tugcu et al. (2012), examines relationship between renewable and non-renewable energy consumption and economic growth. This paper also uses both classical and augmented production function and employs a multivariate framework. Real gross capital formation, labor force, human capital and R&D variables are included in the analysis. Results show that both renewable and non-renewable energy consumption matters for economic growth and augmented production function is more effective on explaining this relationship.

Kazar and Kazar (2013) use development level instead of economic growth variable and this paper analyze the relationship between electricity production from renewable sources and development level for 154 countries. According to the paper's results in the long run economic development leads renewable energy production but on the other hand there is a bidirectional relationship between them in the short run. Moreover this relationship varies according to the countries human development level.

A different view also came from Menegaki and Ozturk (2013). In this paper energy and growth relationship is analyzed under the political economy perspective and according to the results there is bidirectional causality (feedback hypothesis) between growth and political stability as well as capital and political stability. Therefore the economy's political aspect should not be ignored.

Chen et al. (2007) emphasizes that, the reasons of these diverse results are using different data set and alternative econometric methodologies and different countries characteristics. Each country has different indigenous energy supplies, different political arrangements, different institutional arrangements, different cultures and different energy policies (Chen et al., 2007: 2612). So when these methodologies are applied countries that have different economic background, contradictory results have become inevitable.

4. Data, methodology and results

4.1. Data

The multivariate panel framework includes; real GDP in constant 2005 US dollars, non-renewable energy consumption and renewable energy consumption, real gross fixed capital formation in constant 2005 US dollars, energy technology research and development indicators and greenhouse gas emissions (thousand tones CO_2 eq.).

Energy technology research and development variable includes statistics on energy technology Research & Development and dissemination as well as R&D budget for these countries. It presents shifts in R&D, expenditures associated with investments and further analyzes budget allocations in terms of flow. Most of papers in literature uses CO_2 emissions, this paper differs from previous studies in using greenhouse gas emissions and energy technology research and development variables.

Non-renewable energy consumption constitutes from total petroleum products, natural gas and solid fuels. Renewable energy refers to biomass, hydropower, geothermal energy, wind and solar energy. Both renewable and non-renewable energy consumption are all expressed in 1000 tones of oil equivalent. The raw data about energy consumption are attained from EUROSTAT and real GDP, real gross fixed capital formation in constant 2005 US dollars, energy technology research and development indicators and greenhouse gas emissions' raw data are attained from OECD. Because of relatively short time period, a panel cointegration and error correction model is used to present the causal relationship.

4.2. Unit Root and Cointegration

In the analysis, to ensure robustness for the common components of renewable and non-renewable energy consumption, real GDP (RGDP), real gross fixed capital formation (FIXCAP), energy technology research and development indicators (R&D) and greenhouse gas emissions (GGAS) unit root test is employed.

All variables except $NGAS$, $FIXCAP$, $R\&D$ all in natural logarithm since they have nonxpositive values. Im, Peseran and Shin (2003) unit root test results are presented in Table 2.

According to the unit root test results, we have found that $RGDP$, $SFUELS$, $NGAS$, $TPETROL$, $RNEW$, $FIXCAP$, $R\&D$, $GGAS$ and TOTAL series are stationary in first differences.

Table 2. Im Peseran and Shin Unit Root Test Results

Series	W Statistics (Probabilities)		
	Level	**First Difference**	**Results**
$RGDP$	1.483 (0.931)	-5.943 (0.000)	I(1)
$SFUELS$	-1.384 (0.083)	-9.026 (0.000)	I(1)
$NGAS$	-1.081 (0.139)	-5.691 (0.000)	I(1)
$TPETROL$	2.287 (0.988)	-4.432 (0.000)	I(1)
$RNEW$	10.753 (1.000)	-4.853 (0.000)	I(1)
$FIXCAP$	0.464 (0.678)	-6.630 (0.000)	I(1)
$R\&D$	1.897 (0.971)	-4.617 (0.000)	I(1)
$GGAS$	2.680 (0.996)	-4.493 (0.000)	I(1)
$TOTAL$	1.855 (0.968)	-4.748 (0.000)	I(1)

1) Newey-West bandwidth selection using Bartlett kernel.
2) Individual Effects

Due to the VAR lag order selection criteria, it is found that lag length is 1. We use the Hannan Quinn information criteria and Schwarz information criteria that is the mostly used in the literature. Having verified that the series are non stationary and same order integration as I(1), it is tested whether there exist any long run equilibrium relationship between the variables using Panel Cointegration.

Table 3. Panel Cointegration Tests

Within Dimension Test Statistics		Between Dimension Test Statistics	
Panel v-statistics	7.322(0.000)*	Group p-statistics	2.369(0.991)
Panel p-statistics	1.113(0.862)	Group PP-statistics	-1.939(0.026)*
Panel PP-statistics	-2.275(0.011)*	Group ADF-statistics	-3.817(0.000)*
Panel ADF-statistics	-3.215(0.000)*		

Notes: Probability values are in parenthesis. Out of the seven tests, excluding Panel p-statistics and Group p-statistics all remaining tests reject the null hypothesis of no cointegration at the 5% significance level.

We have seen from the Pedroni Panel Cointegration test, five out of seven statistics reject the null hypothesis of no cointegration. That is, there is a long run relationship between the variables (table 3).

In the next step, the fully modified OLS (FMOLS) technique for heterogeneous cointegrated panels is estimated (Pedroni, 2000) and four different models are estimated. Table 4 shows this FMOLS results. Since all variables are expressed in natural logarithm, variables' coefficients can be interpreted as elasticity.

Table 4. Panel FMOLS Estimation

Models	Estimations (t values in paranthesis)
Panel A	$RGDP = 0.001RNEW - 0.79TOTAL + 3.02GGAS - 0.93R\&D$ (22.13) (2.91) (6.22) (-3.36)
Panel B	$RGDP = -0.93TOTAL + 2.56GGAS - 1.24R\&D$ (-7.53) (9.70) (-5.91)
Panel C	$RGDP = 0.001RNEW + 1.21TOTAL - 0.71R\&D$ (24.99) (10.06) (-3.34)
Panel D	$RGDP = 0.002RNEW - 0.004SFUELS + 0.003TPETROL$ (19.86) (-4.88) (15.66)

According to panel A; the elasticity of renewable energy consumption on real GDP is positive and statistically significant. However, renewable energy consumption's effect on real GDP is very small. Total non-renewable energy consumption has a negative impact on economic growth in Panel A. Together with evaluating the Panel D, it can be seen that total petroleum consumption impact is 0.003, on the other hand solid fuels impact is -0.004 that is slightly larger than elasticity of total petroleum so solid fuels negative impact is more dominant. Greenhouse gas emissions has a positive impact on real GDP, it can be said that a 1 % increase in greenhouse gas emissions increases real GDP by 3.02 % (Panel A). In each of the three models Panel A,B,C research and development has a negative impact on real GDP, 1 % increase in R&D decreases real GDP by 0.93 %(Panel A).

4.3. Causality and Results

To infer the causal relationship between the variables, a panel vector error correction model (Pesaran et al., 1999) is estimated to perform Granger-causality tests. VECM Granger Causality Test result is illustrated in Table 5. Due to this result we have all the probabilities are less than 0.05 except R&D. Research and development does not (granger) cause the real GDP. Thus, Solid fuels plus total petroleum (granger) cause the real GDP. Finally, green gas (granger) causes the real GDP. The error correction term is statistically significant at the 5 % level with the speed of adjustment to long run equilibrium of 1,12 years.[3]

Table 5. Panel Causality Test Results

Dependent Variable	$\Delta RGDP$	$\Delta GGAS$	$\Delta TOTAL$	$\Delta R\&D$	Long-Run ECT
$\Delta RGDP$	-	**44.014* (0.000)**	**44.151* (0.000)**	**0.469 (0.626)**	**-0.888 [-11.161]**
$\Delta GGAS$	0.041 (0.959)	-	0.215 (0.806)	2.130 (0.120)	-0.0001 [-0.063]
$\Delta TOTAL$	0.014 (0.985)	1.417 (0.244)	-	0.542 (0.581)	-0.0001 [-0.007]
$\Delta R\&D$	5.168* (0.006)	3.693* (0.026)	3.016* (0.05)	-	0.002 [2.001]

5. Conclusion

This paper's aim is to analyze the long-run and causal relationship between renewable and non-renewable energy consumption and economic growth using panel data for 15 European Union countries over the period 1990-2011 within a multivariate framework. The relationship indicates that an increase in renewable energy consumption leads an increas in real GDP and there is a positive relationship between greenhouse gas emissions and real GDP. Non-renewable energy consumption has a negative impact on real GDP, in other words an increase in non-renewable energy consumption decreases real GDP. When non-renewable energy is seperated as total petroluem and solid fuels, the impact has become different. Solid fuelds has a negative impact on real GDP on the other hand total

[3] The speed of adjustment in terms of years is simply the reciprocal of the absolute value of the error correction coefficient estimate.

petroluem has an positive impact on real GDP. So it can be said that solid fuels consumption does not yield economic growth. On the other hand total petroleum causes economic growth but its negative impact on the environment can be observed as an increase in greenhouse gas emissions.

In the model Research and Development about energy technology has a negative impact on real GDP. It can be said that the investment on energy technology has not yield advantages yet, current financial crisis might decrease the investments in this sector and because of this, and research and development has not reached the threshold point to increase the real GDP.

According to causal relationships between non-renewable energy consumption and economic growth there exists uni-directional causality between them and it is from non-renewable energy consumption to economic growth. According to causal relationships between greenhouse gas emissions and economic growth there is also a uni-directional relationship between them and it is similarly from greenhouse gas emissions to economic growth. According to these results growth hypothesis is present for EU-15 countries. First of the famous 20/20/20 target is, %20 savings in energy consumption. According to the results this target might affect EU-15's growth adversely. So, to achieve this target both household and industry should substitute their non-renewable energy demand with renewable energy. Last but not least, it can be said that currently these countries faces a trade-off between non-renewable energy consumption with climate change and environment and to overcome this challenge can be possible only doing more investment and innovation in renewable energy sector.

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