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Economic growth and energy consumption in 12 European countries: a panel data approach

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Abstract. The paper investigates the relationships between energy consumption and economic growth for 12 European countries over 13 years using data for the sample period of 2000 to 2012. Understanding the relationships of energy consumption in relation to the economy is very important task to ensure a stable economic development. The hypothesis of the study says that there is a positive relationship between energy use and economic growth.

The estimation of GDP equation indicated that that the energy consumption is positive related to the economic growth. The evaluated regression model includes growth rates of Energy Consumption and growth rates of Gross Fixed Capital in real prices. The analysis let to state that in the analyzed countries energy consumption is not neutral to economic growth. Furthermore, the applied modeling pointed the individual growth rate effect of GDP for every country, that was not captured by the estimated model.

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INTRODUCTION

The relationship between energy consumption and economic growth has been an area of interest in the energy economics literature over the past two decades. Most empirical studies conclude that there is a strong relationship between the two variables and energy consumption can be very helpful by estimating economic growth. Ferguson in 1997, in a research program on the benefits of electricity generation showed that for the G7 group of countries as a whole (USA, Japan, Germany, France, UK, Italy and Canada), constituting two-thirds of the global economy, there was a well correlated relationship between electricity use and wealth creation. Ferguson, Wilkinson and Hill (2000) found correlation between wealth creation and electricity use in 100 developing countries. The correlation was even stronger between wealth and electricity use then between total energy consumption and wealth. Ayres and Voudouris (2014) demonstrated nonlinear relationships between capital, labor, useful energy and economic growth by examining the economic growth of UK, Japan and US during the 20th century. The major conclusion of their study was quite simple that an increasing supply of affordable useful energy is a precondition for continued growth. This means that future economic growth presupposes the availability of increasing quantities of useful energy. So they concluded that traditional computable general equilibrium models make unwarranted assumptions that economic growth is driven only by the accumulation of capital per worker.

The findings stay strong opposite to the neo-classical economic worldview, where the economy is seen as a closed system within which goods are produced only by inputs of capital and labor, and then exchanged between consumers and firms. The economic growth is achieved by increasing inputs of labor or human capital (Hall, Cleveland, Kaufmann, 1986).

The aim of this paper is to empirically investigate the relationships between energy consumption and economic growth for 12 countries of Europe over 13 years, using data from the Eurostat databases for the sample period of 2000 to 2012. Understanding the relationships of energy consumption in relation to the economy is very important task to ensure a stable economic development. The hypothesis of the study is: there is positive relationship between energy use and economic growth, what is typical for modern human economies (Shafiee and Topal 2008, Smil 2008, Payne 2010). So, the energy consumption is a significant explanatory variable in GDP equation.

The remainder of the paper is organized as follows. Section 2 describes the model and the econometric methodology used in the analysis. Section 3 reports the data employed in this study and the empirical results. Finally, conclusions are made in Section 4.

THE METHOD AND THE MODEL

In the present study, we use the panel data approach to investigate the relationship between energy consumption and economic growth. We propose a framework based on the conventional neo-classical one-sector aggregate production function, where we treat Energy Consumption (E), Capital (K) and Total Employment (L), as separate inputs in GDP equation. That is:

$$GDP = f\left(K,\ L,\ E\right) \tag{1}$$

$$GDP_{i,t} = \beta_0 + \sum_{j=0}^{n}\beta_{1j}K_{i,t-j} + \sum_{j=0}^{n}\beta_{2j}L_{i,t-j} + \sum_{j=0}^{n}\beta_{3j}E_{i,t-j} + \mu_{i,t} \tag{2}$$

where:

GDP= ln of Gross Domestic Product
K= ln of Gross Fixed Capital
E= ln of Total Energy Consumption
L= ln of Total Employment

The methodology adopted in this study uses a two-step procedure. First, panel unit root tests are applied to test the degree of integration of economic growth and energy consumption. Second, panel least squares method is applied to determine the significant relationships between energy consumption and GDP. The empirical study was made using EViews software. EViews provides convenient tools for computing panel unit root tests. We computed the following tests: Levin, Lin and Chu (2002), Im, Pesaran and Shin (2003), Fisher-type tests using ADF and PP tests—Maddala and Wu (1999), Choi (2001).

EMPIRICAL RESULTS

Data and variables definitions

The data for calculation was taken from Eurostat databases. The financial data was adapted to reality with the use of Eurostat price indices. Then data were converted to their logarithms which allowed to present the relationships between variables in an additive equation. The research covers the period from the 2000 to 2012 for 12 European countries given in table 1.

Table 1

Countries under investigation

Czech Republic	CZ
Germany	DE
Ireland	IE
Spain	ES
France	FR
Italy	IT
Austria	AT
Poland	PL
Portugal	PT
Finland	FI
Sweden	SE
United Kingdom	UK

The variables' notations are as follows:
GDP – Gross Domestic Product in real prices,
E – Total Energy Consumption,
K – Gross Fixed Capital in real prices,
L – Total employment.

Test results for unit roots

Before conducting any further analysis, the applied time series were examined by unit root tests. The tests are needed because the applied panel least squares method assumes the stationarity of the analyzed time series. Table 2 reports the results of testing for unit roots in the level variables as well as in their first difference.

In the first half of the table the null hypothesis that each variable has a unit root cannot be rejected. However, after applying the first difference, three of the variables meet the requirements of the study. So, we can acknowledge their stationarity for the 95% confidence interval. Only in the case of Total Employment (L) is there no confidence about the lack of unit root, which results in applying the second difference. After applying the second difference we can acknowledge the stationarity for Total Employment, but the economic interpretation of the two times differenced variable is problematic.

Table 2

Test results for unit roots

	GDP			ΔGDP		
Method	Statistic	Prob.	Obs	Statistic	Prob.	Obs
Null: Unit root (assumes common unit root process)						
Levin, Lin & Chu t*	-1.59356	0.0555	132	-5.50780	0.0000	120
Null: Unit root (assumes individual unit root process)						
Im, Pesaran and Shin W-stat	1.91260	0.9721	132	-2.25823	0.0120	120
ADF - Fisher Chi-square	11.2021	0.9875	132	39.1055	0.0266	120
PP - Fisher Chi-square	8.25611	0.9988	144	49.1941	0.0018	132
	E			ΔE		
Method	Statistic	Prob.	Obs	Statistic	Prob.	Obs
Null: Unit root (assumes common unit root process)						
Levin, Lin & Chu t*	-1.29987	0.0968	132	-1.91937	0.0275	120
Null: Unit root (assumes individual unit root process)						
Im, Pesaran and Shin W-stat	1.96734	0.9754	132	-1.85920	0.0315	120
ADF - Fisher Chi-square	10.8342	0.9901	132	36.4487	0.0496	120
PP - Fisher Chi-square	27.6316	0.2759	144	130.068	0.0000	132
	K			ΔK		
Method	Statistic	Prob.	Obs	Statistic	Prob.	Obs
Null: Unit root (assumes common unit root process)						
Levin, Lin & Chu t*	-2.91024	0.0018	132	-5.27010	0.0000	120
Null: Unit root (assumes individual unit root process)						
Im, Pesaran and Shin W-stat	0.76137	0.7768	132	-2.54684	0.0054	120
ADF - Fisher Chi-square	21.1991	0.6270	132	44.2347	0.0072	120
PP - Fisher Chi-square	12.6627	0.9714	144	49.3894	0.0017	132
	L			ΔL		
Method	Statistic	Prob.	Obs	Statistic	Prob.	Obs
Null: Unit root (assumes common unit root process)						
Levin, Lin & Chu t*	-2.36603	0.0090	132	-2.89529	0.0019	120
Null: Unit root (assumes individual unit root process)						
Im, Pesaran and Shin W-stat	0.84303	0.8004	132	-1.12588	0.1301	120
ADF - Fisher Chi-square	25.1078	0.3999	132	31.8784	0.1300	120
PP - Fisher Chi-square	6.53630	0.9998	144	35.0939	0.0670	132

	ΔΔL		
Method	Statistic	Prob.	Obs
Null: Unit root (assumes common unit root process)			
Levin, Lin & Chu t*	-5.78786	0.0000	108
Null: Unit root (assumes individual unit root process)			
Im, Pesaran and Shin W-stat	-3.14789	0.0008	108
ADF - Fisher Chi-square	50.8112	0.0011	108
PP - Fisher Chi-square	124.732	0.0000	120

Source: Own calculation.

Panel least squares estimation results

In studying relationships between energy consumption and GDP we applied panel least squares method. There were estimated equations of GDP, taking into consideration one way models with fixed or random cross-section effects. The final form of estimated equation is as follows:

$$\Delta GDP_{i,t} = \beta_0 + \sum_{j=0}^{n}\beta_{1j}\Delta K_{i,t-j} + \sum_{j=0}^{n}\beta_{2j}\Delta\Delta L_{i,t-j} + \sum_{j=0}^{n}\beta_{3j}\Delta E_{i,t-j} + \mu_{i,t} \qquad (3)$$

The results of modeling the equation are reported in Table 3, which presents the econometrical tests of the estimated models as well. Results were obtained using EViews software.

Table 3

ΔGDP modeling

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.015900	0.001106	14.37793	0.0000
ΔE	0.144773	0.034123	4.242637	0.0000
ΔK	0.275084	0.019327	14.23308	0.0000
ΔΔL	0.148327	0.074422	1.993050	0.0486
Effects Specification				
Cross-section fixed (dummy variables)				
R-squared	0.824997	Mean dependent var		0.015784
Adjusted R-squared	0.804056	S.D. dependent var		0.028380
S.E. of regression	0.012562	Akaike info criterion		-5.809577
Sum squared resid	0.018464	Schwarz criterion		-5.481986
Log likelihood	398.4321	Hannan-Quinn criter.		-5.676459
F-statistic	39.39714	Durbin-Watson stat		1.828446
Prob(F-statistic)	0.000000			

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.015904	0.002438	6.523866	0.0000
ΔE	0.146163	0.034023	4.296049	0.0000
ΔK	0.274864	0.019114	14.37994	0.0000
ΔΔL	0.147911	0.074233	1.992522	0.0484
Effects Specification				
			S.D.	Rho
Cross-section random			0.007526	0.2641
Idiosyncratic random			0.012562	0.7359
Weighted Statistics				
R-squared	0.789447	Mean dependent var		0.007096
Adjusted R-squared	0.784512	S.D. dependent var		0.026778
S.E. of regression	0.012431	Sum squared resid		0.019778
F-statistic	159.9739	Durbin-Watson stat		1.707092
Prob(F-statistic)	0.000000			
Unweighted Statistics				
R-squared	0.763366	Mean dependent var		0.015784
Sum squared resid	0.024967	Durbin-Watson stat		1.352353

Test cross-section fixed effects			
Effects Test	Statistic	d.f.	Prob.
Cross-section F	3.743511	(11,117)	0.0001
Cross-section Chi-square	39.804727	11	0.0000
Test cross-section random effects			
Test Summary	Chi-Sq. Statistic	Chi-Sq. d.f.	Prob.
Cross-section random	0.328479	3	0.9546

Source: Own calculation.

The results of the estimation of GDP equation appears to be a little confusing. Notice that there are two sets of tests made by modeling. The first set consists of two tests - Cross-section F and Cross-section Chi-square - that evaluate the joint significance of the cross-section effects using sums-of-squares (F-test) and the likelihood function (Chi-square test). The two statistic values (3.743511 and 39.804727) and the associated p-values strongly reject the null hypothesis that the cross-section effects are redundant. On the other hand the second test was Hausman test. A central assumption in case of random effects estimation is the assumption that the random effects are uncorrelated with the explanatory variables. One common method for testing this assumption is to employ a test to compare the fixed and random effects estimates of coefficients (Hausman, 1978). The statistic provides evidence that there is no reason to reject the null hypothesis that there is no misspecification.

After testing it appears that we have here a situation, where the cross-section effects could be treated as fixed effects as well as random effects. The good practices in such situations says that when we have a model, where we are seeking some dependences in countries level then we should choose fixed cross-section effects. Second we should take the statistics of evaluated models into account. When we do this it becomes obvious that the first equation of GDP is the right one.

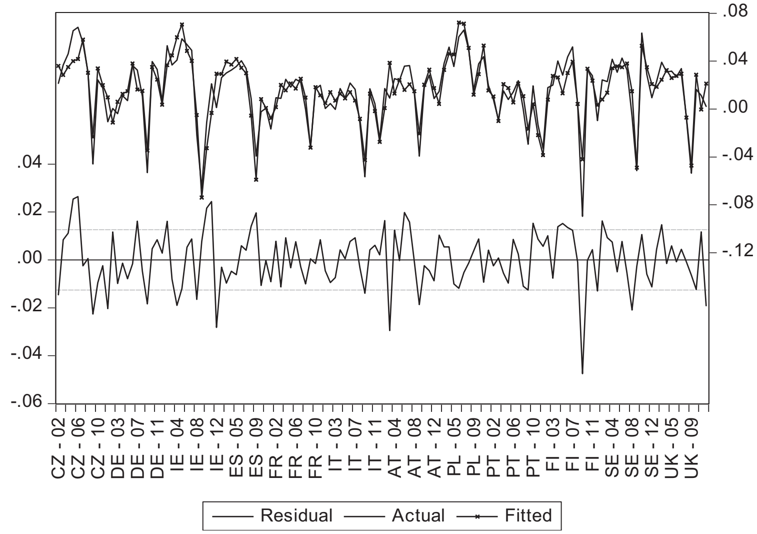

Diagram 1. Residuals, actual and fitted data by ΔGDP Model 1
Source: Own calculation.

The adjusted R-squared is higher than in second equation (0.804 > 0.784), so the first model better fits the actual data. The estimated DW test statistic for the model is 1.828, so we can state that the residuals are uncorrelated and the heteroscedasticity of residuals is not present. Furthermore, the residual PAC correlogram was made taking 4 quarters lag into consideration. The results are presented in Table 4. The analysis confirms that the residuals are uncorrelated.

Table 4

Autocorrelation testing

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	0.063	0.063	0.5401	0.462
		2	-0.093	-0.098	1.7281	0.421
		3	-0.115	-0.104	3.5408	0.316
		4	-0.061	-0.058	4.0628	0.398

Source: Own calculation.

The calculation of confidence intervals and various significance tests for coefficients are all based on the assumptions of normally distributed residuals. Sometimes, the residual distribution is distorted by the presence of a few large outliers. Since the parameter estimation is based on the minimization of squared error, a few extreme observations can exert a disproportionate influence on parameter estimates. If the error distribution is significantly non-normal, confidence intervals may be too wide or too narrow. For this reason, we conducted a test for the normality of residuals (Diagram 2).

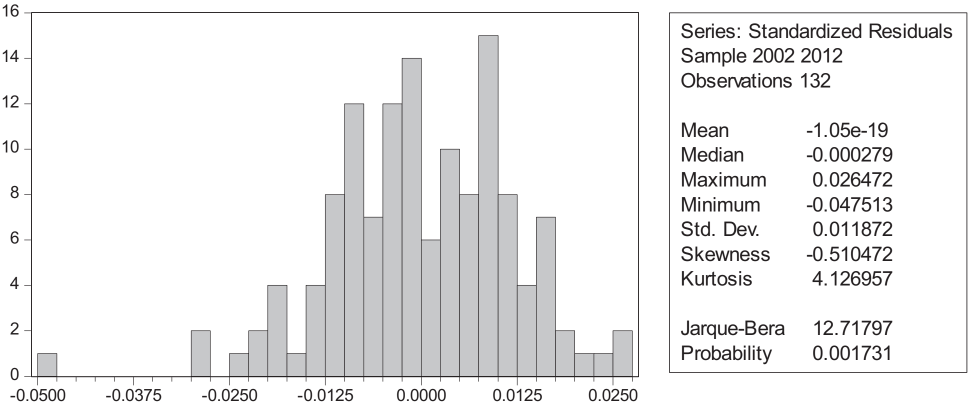

Diagram 2. Normality of residuals

Source: Own calculation.

The the Jarque-Bera statistic rejects the hypothesis of normal distribution. The p-value is low, so it indicates that there is no reason to confirm the null hypothesis. So we have recalculated the equation using panel EGLS (Cross-section weights) to meet the assumptions of regression. The equation is given in table 4.

The estimated DW test statistic for the model is 1.877, so we can state that the residuals are uncorrelated and the heteroscedasticity of residuals is not present. Furthermore, the residual PAC correlogram was made taking 4 quarters lag into consideration. The results are presented in Table 5. The analysis confirms that the residuals are uncorrelated.

Table 4

ΔGDP equation

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.015703	0.000902	17.41344	0.0000
ΔE	0.118406	0.031500	3.758902	0.0003
ΔK	0.283793	0.018172	15.61693	0.0000
$\Delta\Delta$L	0.080887	0.064835	1.247576	0.2147
	Effects Specification			
Cross-section fixed (dummy variables)				
	Weighted Statistics			
R-squared	0.863944	Mean dependent var		0.017426
Adjusted R-squared	0.847663	S.D. dependent var		0.031861
S.E. of regression	0.012444	Sum squared resid		0.018119
F-statistic	53.06698	Durbin-Watson stat		1.877418
Prob(F-statistic)	0.000000			
	Unweighted Statistics			
R-squared	0.822329	Mean dependent var		0.015784
Sum squared resid	0.018746	Durbin-Watson stat		1.807358

Source: Own calculation.

Table 5

Autocorrelation testing

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	0.078	0.078	0.8246	0.364
		2	-0.133	-0.140	3.2287	0.199
		3	-0.103	-0.082	4.6742	0.197
		4	-0.036	-0.040	4.8514	0.303

Source: Own calculation.

We conducted a test for the normality of residuals as well. The results are presented on diagram 3.

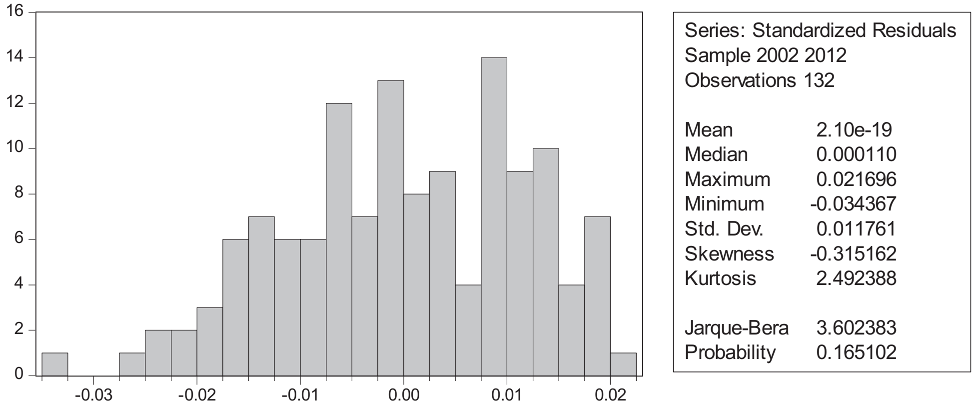

Diagram 3. Normality of residuals

Source: Own calculation.

This time the Jarque-Bera statistic does not reject the hypothesis of normal distribution. The p-value is 0.165, so it indicates that there is no reason to reject the null hypothesis and allows us to accept the normality of residuals.

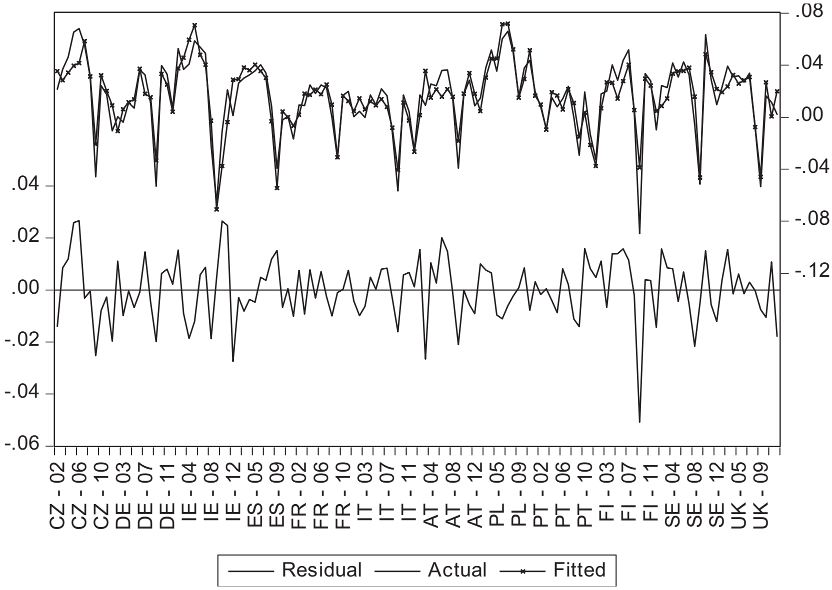

Diagram 4. Residuals, actual and fitted data by ΔGDP final equation

Source: Own calculation.

The modeling we carried out meets all the requirements of a proper estimation. The residuals of the model have normal distribution with the expected value 0. In addition, we used stationary variables for the estimation of the equation .The estimated model of economic growth with the application of energy consumption as one of the explanatory variables meets all the conditions of proper estimation, so it undoubtedly has reliable economic interpretation.

CONCLUSIONS

In the study, we attempted to analyze the relationships between energy consumption and economic growth for 12 European countries. The analysis was based on panel least squares modeling. The estimation of GDP equation indicated that that the energy consumption is positive related to the economic growth.

The final GDP equation excludes Total Employment, what stands in line with the previous studies in the subject (Kasperowicz, 2013). The evaluated regression model includes growth rates of Energy Consumption and growth rates of Gross Fixed Capital in real prices. The analysis let us to state that in the analyzed countries energy consumption is not neutral to economic growth. The Energy Consumption is a pro-growth variable, which means that the increase of the energy consumption causes the increase of economic growth. The conclusion stands in contradiction to the neo-classical argument that energy is neutral to output growth. The second significant variable – Gross Fixed Capital is a pro-growth variable as well. The increase of the capital causes the increase of economic growth in the analyzed countries. The above-mentioned variables make up a regression equation, which explains about 86% of the variability of the economic growth in analyzed countries. The applied panel modeling with cross-section fixed effects let to point the individual effect for every country, that was not captured by the estimated model (the effects are given in table 6).

Table 5

Individual effects

	LAND	Effect
1	CZ	0.007068
2	DE	-0.004874
3	IE	0.015056
4	ES	0.001337
5	FR	-0.007526
6	IT	-0.010886
7	AT	-0.002307
8	PL	0.009718
9	PT	-0.000809
10	FI	-0.003534
11	SE	-0.002243
12	UK	-0.001000

Source: Own calculation.

The individual effects show the part of growth rate of economic growth of a country that is not calibrated in the model. So we have here some other information about the results. For example - the characteristics of Polish economy that was not included in the model affected the Polish economic growth rate so that the

Polish economic growth rate was about 0.01 (0.009718) higher than the average economic growth rate in analyzed countries. Analogously can be interpreted fixed effect for other countries.

To sum up, the empirical results of the study show that the economic growth of analyzed European countries is energy-dependent, so one can state that energy consumption is a limiting factor to economic growth. However, the results obtained should be considered very carefully, because the results have been achieved on the basis of a limited, small number of observations of independent variables. The studies should be counted as a preliminary study for further reflection on the subject.

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