Theoretical and Applied Economics
Volume XXVIII (2021), No. 1(626), Spring, pp. 151-166

Energy and economic growth. An empirical analysis

Antonios ADAMOPOULOS
University of Western Macedonia, Greece
adonios23@yahoo.gr

Abstract. *This study investigates the interrelation between energy and economic growth for USA covering the time period from 1975 to 2017. Ordinary least squares method and the essential diagnostic tests are applied in order to examine the possible existence of autocorrelation, specification, heteroscedasticity and normality tests for residuals of estimated equation model. The empirical results of this study indicated that there is a linear and positive relationship between energy and economic growth for USA.*

Keywords: energy, economic growth, Ordinary least squares method, unit roots theory.

JEL Classification: O11, C22, Q40.

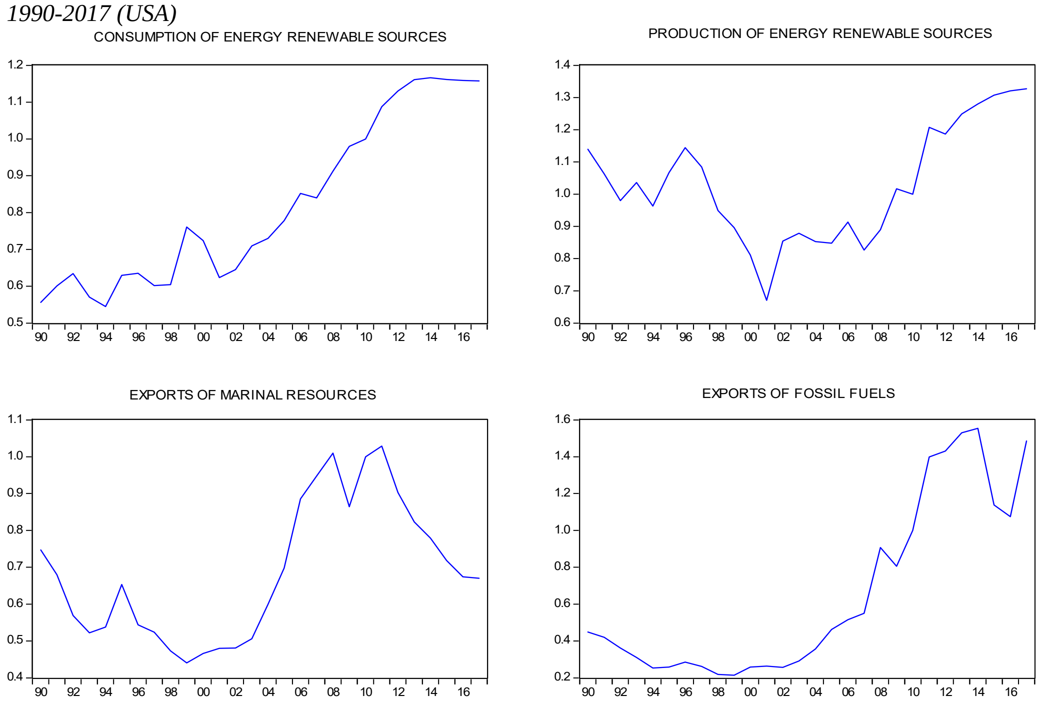
1. Introduction

The investigation of interrelation between energy and economic growth consists an important issue in the modern literature. Following the empirical studies of Hall et al. (2001), Hondroyannis et al. (2002), Stern and Cleveland (2004), it can be inferred that the energy sector encourages economic growth, through the exploitation of natural and mineral resources. Therefore, the use of energy facilitates the production from renewable sources and energy consumption respectively.

Specially, USA is regarded as a leader country in utilization of renewable energy resources the last decades, since tends to substitute highly the excessive consumption of electric power by alternative and energy nuclear. Also, USA one of the most developed countries worldly, is regarded as a dominant economy in energy sector and is mainly focused on exports of petroleum and gas fuels overcoming its competitors such as Russia and Saudi Arabia.

The energy consumption, the production renewable energy resources and the exports of mineral and fossil fuels in USA has raised remarkably from 1990 to 2017 as it seems in Figure 1.

Figure 1. *Consumption and electricity production from renewable sources exports of mineral resources 1990-2017 (USA)*



The ultimate goal of this study is to define the direct effect of energy growth on economic growth taking into account the positive effect of different energy resources such as alternative and nuclear energy and the use of renewable energy sources. The exploitation and the use of renewable energy sources can cause limitations of carbon dioxide (CO_2) emissions preventing the pollution of the environment.

The consumption and the production from energy renewable sources have increased rapidly the last decade in USA in conjunction with the substitution of electric power and the utilization of alternative energy sources. Exports and domestic production of USA have been augmented due to the higher demand of energy and the exploitation of its natural resources. The basic hypothesis of regression model defines that energy use, alternative and nuclear energy, electricity production from renewable sources and exports of mineral resources have a positive effect on gross domestic product in USA for the examined period 1975-2017.

This empirical study has the following objectives:

a) To examine the interrelation between energy and economic growth.

b) To estimate a linear equation model with ordinary least squares method in order to find out the existence or no of model linearity.

c) To investigate the presence of statistical significance of model variables by applying diagnostic tests like autocorrelation, specification, heteroskedasticity and normality tests of residuals.

2. Literature review

The relationship between energy and economic growth has aroused an extensive academic interest in modern literature. Chontanawat et al. (2008) suggested that there is unidirectional causality from energy to economic growth in the developed OECD countries due to the reduction policy of carbon dioxide emissions to the environment and the limitations of excessive usage of energy resources. Sadorsky (2009) ascertained the positive and statistically significant effect of per capita income on renewable energy consumption estimating a linear model with panel analysis for 18 emerging countries.

Sari et al. (2008) estimated an autoregressive distributed lag (ARDL) model in order to find out the nexus between energy consumption and economic growth taking into account the effect of employment on economic growth in USA. The empirical results of their study revealed that the long-run equilibrium and the short- run fluctuations could be incorporated into the demand management strategies of energy market producers and policy makers.

Apergis and Payne (2011) examined the causal relationship between renewable energy consumption and economic growth for a panel of six Central American countries covering the time period from 1980 to 2006. The empirical results of their study indicated that there is a bidirectional causality between renewable energy consumption and economic growth both in the short-run and the long-run. Belke et al. (2011) certified that there is a bidirectional causality between energy consumption and economic growth for 25 OECD countries from 1981 to 2007. Moreover, Apergis and Payne (2012) found bidirectional causal nexus between renewable and non-renewable energy consumption-growth estimating a heterogeneous panel model analysis for 80 countries for the period 1990-2007.

Lau et al. (2011) confirmed that there is a long-run equilibrium relationship between energy consumption and economic growth for seventeen Asian countries. They supported that energy consists an impetus of economic growth in the short-run but in the long-run, the energy consumption is fundamentally driven by economic growth. The energy conservation promotes sustainable economic development and contributes to environmental growth.

Menegaki (2011) investigated the causal relationship between economic growth and renewable energy for 27 European countries estimating a panel analysis based on a random effect model for the time period 1997-2007. In the opposite, she ascertained the neutrality hypothesis in causality analysis both in the short-run and long-run, implying that the consumption of renewable energy didn't play an effective role in economic growth in Europe, maybe due to the inefficient exploitation of energy resources and the early stages of development of renewable energy as well.

Destek (2016) examined the relationship between renewable energy consumption and economic growth in newly industrialized countries for the period from 1971 to 2011. The empirical results of asymmetric causality revealed negative shocks in renewable energy consumption caused positive shocks in economic growth for South Africa and Mexico, but negative shocks in economic growth for India, while the neutrality hypothesis of causality was confirmed for Brazil and Malaysia.

Jebli et al. (2016) verified the environmental Kuznets curve hypothesis studying the causality between per capita CO_2 emissions, gross domestic product (GDP), renewable and non-renewable energy consumption, and international trade for a panel of 25 OECD countries over the period 1980-2010. They concluded that renewable energy and trade have a negative impact on per capita CO_2 emissions caused by non-renewable energy resources. Furthermore they inferred that there is a bidirectional causality between energy and economic growth in the long run.

Finally, Adamopoulos and Kalogeridis (2019) resulted that energy consumption has a positive direct effect on economic growth, estimating a structural system equation model for Sweden covering the period from 1995 to 2015. The remainder of the paper proceeds as follows: Section 3 describes the data methodology of empirical study, while section 4 analyses the empirical results. Finally, section 5 provides the conclusions of this paper.

3. Data analysis and methodology

A linear regression model adopted to estimate the long-run effect of energy growth on economic growth. For this reason, an ordinary least squares method is applied in order to find out the interrelation between the examined variables, based on economic theory. The general form of the linear equation model is the following one:

$$GDP_t = c_1 + c_2 EN_{t-2} + c_3 ALTER_{t-1} + c_4 EL\_PROD\_REN_t + c_2 X_t + u_{1t} \quad (1)$$

where:
GDP – Gross Domestic Product.
EN – Energy use.
ALTER – Alternative and nuclear energy.

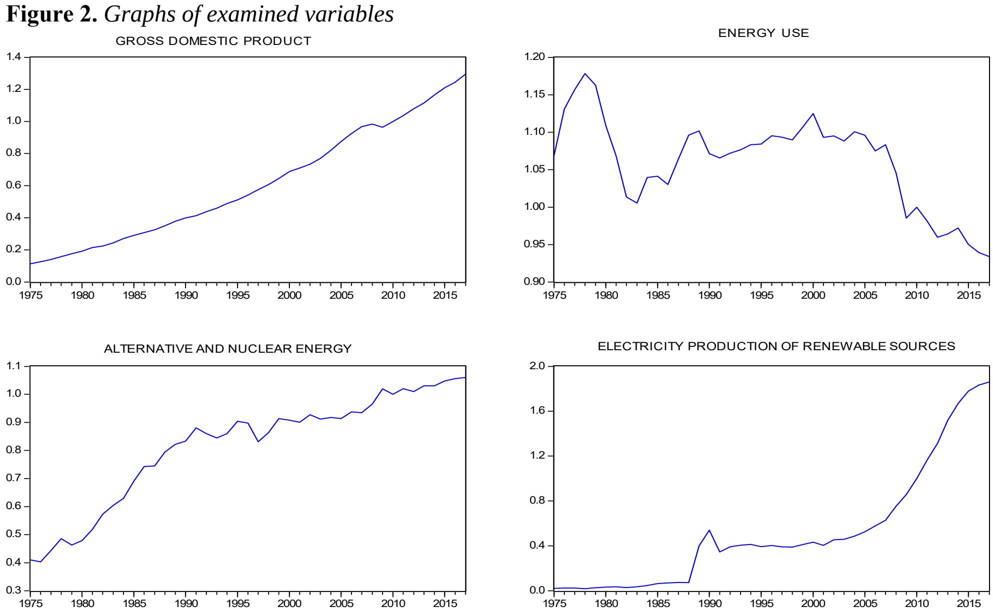
EL_PROD_REN – Electricity production from renewable sources.
X – Exports of mineral resources.
t – time trend.
t-i – lagged time trend.
u – residual (error term).
$c_{1,...,} c_{21}$ – estimated coefficients.

Based on the studies of Katos et al. (1996), Hall et al. (2001), Katsouli (2006), Stern and Cleveland (2004), Vazakidis (2006), Apergis and Payne (2011), Adamopoulos and Kalogeridis (2019), the variable of economic growth (GDP) is measured by the real gross domestic product, while energy growth is represented by electricity production from renewable sources (EL_PROD_REN), energy use (EN), alternative and nuclear energy (ALTER).

In this empirical study annual data are used in the matter of Sweden, while the time period ranges from 1975 to 2017. Data have been obtained from the statistical database of World Bank (World Development Indicators online database). All data variables has been transformed in constant prices regarding 2010 as a base year. Eviews 10.0 (2017) software package is used to conduct the empirical results.

Statistical diagnostic tests such as autocorrelation, specification, heteroskedasticity and normality tests of residuals of the estimated model are examined in this linear regression model. The graphs of model variables are presented in Figure 2.

Figure 2. *Graphs of examined variables*



The higher rate of GDP, alternative and nuclear power, electricity production from renewable sources achieved in 2017, while the lower one was remarked in 1975 respectively.

3.1. Unit roots theory

According to Choi (1992), the Phillips-Perron test appears to be more powerful than the Augmented Dickey-Fuller test (Dickey and Fuller, 1979) for the aggregate data. Phillips-Perron (1988) unit root test can be used for stationarity testing for the existence of autocorrelated and heteroscedastic residuals as follows:

$$\ln(1+r) = a + b\left(\frac{t-T}{2}\right) + d\ln(1+r_{t-1}) + e_t \tag{2}$$

for t = 1, 2,…,T where r_t denotes interest rate at time t, (t-T/2) is a time trend and T is the sample size (Laopodis and Sawhney, 2007).

Equation 5 examines three hypotheses: The first hypothesis supposes that the time series contains a unit root either with a drift or both with a drift and a time trend: H_0^1 : d = 1. The second hypothesis suggests that the time series contains a unit root without a time trend: H_0^2: b = 0, d = 1. The third hypothesis defines that the time series contains a unit root without a drift or a time trend: H_0^3 : a = 0, b = 0, d = 1. The statistics tests that are used to examine each hypothesis separately are $z(t_\delta)$, $z(f_2)$, $z(f_3)$, respectively and are presented in the following equations:

$$z(t_d) = \left(\frac{s_0}{s_{Tl}}\right)t_s - \left(\frac{T^3}{3^{1/2}4D_{xxsTl}^{1/2}}\right)(s_{Tl}^2 - s_0^2) \tag{3a}$$

$$z(f_3) = \left(\frac{s_0^2}{s_{Tl}^2}\right)f_3 - \left(\frac{1}{2s_{Tl}^2}\right)(s_{Tl}^2 - s_0^2)\,\mathrm{x}\left[T(d-1) - \left(\frac{T^6}{48D_{xx}}\right)\left(s_{Tl}^2 - s_0^2\right)\right] \tag{3b}$$

$$z(f_2) = \left(\frac{s_0^2}{s_{Tl}^2}\right)f_2 - \left(\frac{1}{3s_{Tl}^2}\right)(s_{Tl}^2 - s_0^2)\ \mathrm{x}\ \left[T(d-1) - \left(\frac{T^6}{48D_{xx}}\right)\left(s_{Tl}^2 - s_0^2\right)\right] \tag{3c}$$

where:

$$f_3 = \frac{T(s_0^2 - (\bar{r} - \bar{r}_{t-1})^2 - s^2)}{2s^2} \tag{3d}$$

$$f_2 = \frac{T(s_0^2 - s^2)}{3s^2} \tag{3e}$$

s^2 is the residual variance, s_0^2 is the variance under the specific hypothesis for the standard critical t-test for d = 1. D_{xx} is the determinant of the (x'x), where x is the T_3 matrix of independent variables in equations 3a-3e (Laopodis and Sawhney 2007).

Following the studies of Chang and Caudill (2005), Dritsakis and Adamopoulos (2004), Johansen (1988) and Osterwald-Lenum (1992) propose two test statistics in order to find out the number of co-integrated vectors: The trace (λ_{trace}) and the maximum eigenvalue

(λ_{max}) tests statistics. The Likelihood Ratio statistic (LR) for the trace test (λ_{trace}) as proposed by Johansen (1988) has the following form:

$$\lambda_{trace}(r) = -T\sum_{i=r+1}^{p}\ln(1-\hat{\lambda}_i) \qquad (4)$$

where:

$\hat{\lambda}_i$ – the largest estimated value of eigenvalue obtained from the estimated Π matrix.
r – 0, 1, 2,…, p-1.
T – the total number of observations of the examined sample.

The λ_{trace} statistic tests the null hypothesis that the number of distinct characteristic roots is less than or equal to r, (where r is 0, 1, 2 or 3) against the general alternative. The value of λ_{trace} will be smaller when the related values of the characteristic roots are very close to zero.

Alternatively, the maximum eigenvalue (λ_{max}) statistic as suggested by Johansen (1988) has the general form:

$$\lambda_{max}(r, r+1) = -T\ln(1-\hat{\lambda}_{r+1}) \qquad (5)$$

The λ_{max} statistic examines the null hypothesis which defines that the number of co-integrated vectors is r against the alternative of (r + 1) co-integrated vectors. Therefore, the null hypothesis r = 0 is tested against the alternative r = 1, then r = 1 against the alternative r = 2, and finally r = 2 against the alternative r = 3 and so on. If the estimated value of the characteristic root is very close to zero, then the λ_{max} will be smaller respectively (Johansen and Juselious, 1990).

Specifically, Johansen's co-integration tests are very sensitive to the final selection of lag length. The VAR model is fitted to the time series data in order to define an appropriate lag number. The Schwarz Criterion (SC) (1978) is selected as the best statistical criterion in order to find out the eligible number of lags in the co-integration analysis. Table 3 indicates the estimated results from the Johansen co-integration test.

3.2. Ordinary least squares method

Initially, ordinary least squares method is applied to estimate a linear regression model for statistical significance. This method defines that the regression line is fitted to the estimated values by minimizing the sum of squares residuals, which indicates the sum of the vertical distances between each point and the relative point on the regression line. The shorter the distances, the better fitted the regression line. A regression model has a general form as follows:

$$Y_t = a + bX_t \qquad (6)$$

Estimating a regression model with ordinary least squares method, mainly we have to find the estimations of constant term ($\hat{a}$) and the slope of equation model ($\hat{b}$), namely to solve the following patterns (Seddighi et al., 2000; Katos, 2004)

$$\hat{a} = \overline{Y}_t - \hat{b}\overline{X}_t \text{ and } \hat{b} = \frac{n\sum X_t Y_t - \sum X_t \sum Y_t}{n\sum X_t^2 - (\sum X_t)^2} \qquad (7)$$

The final estimated model has the general form as follows (Katos, 2004)

$$\hat{Y}_t = \hat{a} + \hat{b}X_t \qquad (8)$$

3.3. Diagnostics tests

The estimation of a regression model is mainly based on some basic specification tests which employ with existence or non statistical significance problems (Vazakidis, 2006). If the assumptions of these specification tests are not violated then there are not any problems of statistical significance in coefficients and the linear model is very well estimated in accordance with statistical theory. This means that the independent variables of the estimated models have direct effect on dependent variable of the model. The null hypothesis (H0) defines that there is no statistical significance in estimated coefficients of independent variables of the examined model, when the value of probabilities is larger than 5% level of significance, while the alternative (H1) defines that there is statistical significance when the value of probability is lower than 5% level of significance.

In order to examine whether the diagnostics tests are violated we use some statistical tests as Durbin-Watson test statistic for autocorrelation, Breusch-Godfrey-Pagan test statistic for heteroskedasticity, Ramsey Reset test statistic for functional form and Jarque-Bera test statistic for normality test (Ramsey, 1969, Durbin and Watson, 1971, Breusch, 1978, Jarque-Bera, 1980, Engle, 1982). Autocorrelation test refers to the way of residuals are distributed randomly and correlated. Autocorrelation test is violated when the residuals are not distributed correctly around the regression line and are not correlated In order to test autocorrelation we use Breusch-Godfrey (1978) (B-G) test which is regarded more reliable than Durbin and Watson (1971) (D-W) test statistic. The null hypothesis defines that there is no autocorrelation in residuals, while the alternative defines that there is autocorrelation in residuals. We reject null hypothesis when the value of Breusch-Godfrey (BG) test statistic is larger than the value of chi-squared distribution $x^2(2)$ (Breusch, 1978, Godfrey, 1978, Seddighi et al., 2000). In order to correct the existence of autocorrelation problem, we can use the first order autoregression model. The autoregressive coefficient defines that each disturbance equals to a portion of a preceding disturbance plus a random effect expressed by v_t namely

$u_t = \rho u_{t-1} + v_t \quad |\rho| < 1$ where ρ = autoregressive coefficient.

Ramsey (1969) reset test statistic is used for specification test of equation model. The null hypothesis defines that there is correct specification in the equation model, while the alternative defines that there is misspecification. We reject null hypothesis when the value of Ramsey Reset test is larger than the value of chi-squared distribution $x^2(2)$. Breusch-Godfrey-Pagan test statistic is used for heteroskedasticity test. Under heteroskedasticity, the residuals of the estimated model don't have constant variance. The null hypothesis defines that there is homoskedasticity in estimated residuals, while the alternative defines that there is heteroskedasticity. We reject null hypothesis when the value of Ramsey (1969) Reset (RR) test is larger than the value of chi-squared distribution $x^2(2)$ (Breusch and Pagan, 1979; Katos, 2004).

$$BGP = n{*}R^2 = n * \frac{\sum\left(\hat{Y}_t - \bar{Y}_t\right)^2}{\sum\left(Y_t - \bar{Y}_t\right)^2} \qquad (9)$$

Normality test for residuals is examined by Jarque-Bera test statistic. The null hypothesis defines that the residuals are normally distributed in the equation model, while the alternative defines that the residuals are not normally distributed. We reject null hypothesis when the value of Jarque-Bera test statistic is larger than the value of chi-squared distribution $x^2(2)$. Jarque-Bera (1980) (JB) test statistic examines whether the coefficients for skweness and kyrtosis are jointly zero (Seddighi et al. 2000; Katos, 2004).

$$JB = n\left[\frac{m_3^2}{6} + \frac{(m_4 - 3)^2}{24}\right] \text{ where } m_3 = \frac{Eu^3}{s^3} \text{ and } m_4 = \frac{Eu^4}{s^4} \qquad (10)$$

4. Empirical results

The basic statistical measures analyzing the descriptive structure of examined variables as average, mean, standard deviation and coefficients of skewnness and asymmetries are presented in this study for each country respectively in Table 1.

Table 1. *Summary descriptive statistics*

USA	GDP	EN	ALTER	EL_PROD_REN	X
Mean	0.809382	1.047325	0.938632	0.778732	0.686618
Median	0.794750	1.075700	0.915650	0.506200	0.672100
Std. Dev.	0.276850	0.060490	0.072096	0.515904	0.185575
Skewness	0.099406	-0.721557	0.291103	1.107768	0.435167
Kurtosis	1.769712	1.908998	1.813249	2.667453	1.928728

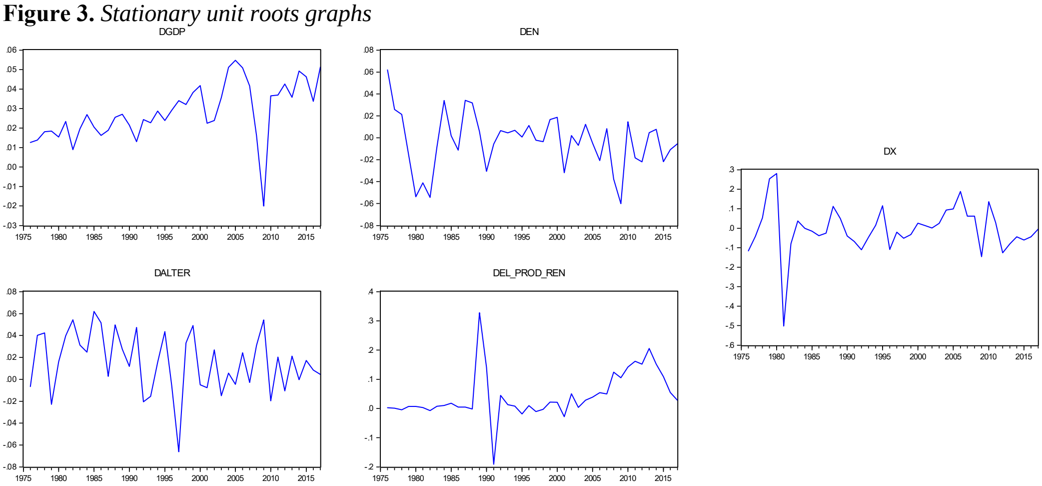
In order to examine the stationarity test of examined variables, Phillips-Perron (1988) unit root test is applied based on Augmented Dickey-Fuller test (ADF) (Dickey and Fuller, 1979). All data variables are stationary in their first differences, so they can be characterized as stationary and integrated of first order (Table 2, Figure 3).

Table 2. *Tests of unit roots hypothesis*

USA	Phillips-Perron (PP_ test stat)		
	t_n	t_c	t_t
GDP	*9.16(lag=1)*	*1.66 (lag=0)*	*-2.09 (lag=4)*
EN	*-1.66(lag=3)****	*0.15(lag=3)*	*-1.10(lag=3)*
ALTER	*1.65 (lag=0)*	*-0.78(lag=0)*	*-3.22(lag=3)*
EL_PROD_REN	*3.75(lag=3)*	*1.98(lag=3)*	*-0.52(lag=2)*
X	*-0.58(lag=2)*	*-1.51(lag=3)*	*-1.91(lag=3)*
DGDP	*-0.88(lag=0)*,**,****	*-3.10(lag=0)**	*-3.43(lag=0)*,***
DEN	*-4.91(lag=3)*	*-5.29(lag=3)*	*-5.48(lag=3)*
DALTER	*-5.58(lag=0)*	*-6.13(lag=0)*	*-6.02(lag=0)*
DEL_PROD_REN	*-3.81(lag=3)*	*-4.27(lag=3)*	*-6.01 (lag=1)*
DX	*-4.15(lag=1)*	*-4.08(lag=1)*	*-4.01(lag=1)**

cr_values in levels: (-3.68, -2.97, -2.65) and in 1st differences (-2.65, -1.95, -1.60) for 1%, 5%, 10% levels of sig.
cr_values for constant and trend in levels and 1st differences are -4.32, -3.56, -3.22
*, **, *** denote not statistical significance in 1%, 5%, 10% level of significance respectively.

Figure 3. *Stationary unit roots graphs*



Then Johansen and Juselious (1990) cointegration tests are applied in order to find out the existence of cointegrated relations between the examined variables. Table 3 indicates that the fitted number of cointegrated vectors is selected every time comparing the relative eigenvalues to the trace and maximum-eigenvalue test statistics for USA based on Schwarz criterion which is more powerful than Akaike criterion.

Table 3. *Johansen and Juselious Cointegration Tests*

USA				
Testing Hypothesis	Johansen Test Statistics			
	Eigenvalue	Trace statistic	Critical values 5%	Prob.
H_0: $r = 0$ and $r=1$	0.8136	137.0792	69.8188	0.0000
H_0: $r \leq 1$ and $r=2$	0.6818	74.9176	47.8561	0.0000
H_0: $r \leq 2$ and $r=3$	0.4976	32.5394	29.7970	0.0236
H_0: $r \leq 3$ and $r=4$	0.1336	7.0658	15.49.47	0.5700
USA				
Testing Hypothesis	Johansen Test Statistics			
	Eigenvalue	Max-eigen statistic	Critical values 5%	Prob.
H_0: $r = 0$ and $r=1$	0.8136	62.1615	33.8768	0.0000
H_0: $r \leq 1$ and $r=2$	0.6818	42.3781	27.5843	0.0003
H_0: $r \leq 2$ and $r=3$	0.4976	25.4736	21.1316	0.0115
H_0: $r \leq 3$ and $r=4$	0.1336	5.3068	14.2646	0.7027

Trace test indicates 3 cointegrating eqn(s) at the 0.05 level.
Max-eigen test indicates 3 cointegrating eqn(s) at the 0.05 level.
* denotes rejection of the hypothesis at the 0.05 level.
**MacKinnon-Haug-Michelis (1999) p-values.

Since all variables are tested for stationarity and cointegration existence, then a simultaneous system equation model is estimated for making simulation policies. The results of Johansen cointegration test indicated that all variables are cointegrated of order one and that there are three cointegrated vectors based on trace and maximum-eigenvalue test statistics for USA. The minimum values of Schwarz criterion determined the number of cointegrated vectors.

The significance of the empirical results is dependent on the variables under estimation. The number of fitted time lags was selected for the best estimation results and to ensure statistical significance in each equation model. Estimating the equation model with ordinary least squares method we can infer that there is statistical significance in coefficients of independent variables, based on probabilities and t-student distribution test statistics. Their estimated values have the expected statistical sign, on the basis of economic theory.

The coefficient of determination in each equation is very high and tends to unity (is close to 0.99), indicating that there is high correlation, so the model is very well adjusted (Table 4).

Table 4. *Ordinary least squares method*

Dependent Variable: GDP				
Sample: 1977-2017				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-1.2021	0.4515	-2.6622	0.0115
EN(-2)	0.7061	0.4151	1.7012	0.0975
ALTER(-1)	0.9164	0.1460	6.2764	0.0000
EL_PROD_REN	0.3834	0.0630	6.0785	0.0000
X	0.1655	0.0966	1.7131	0.0953
R-squared	0.9280	Durbin-Watson stat		0.2954
F-statistic	116.01	Prob(F-statistic)		0.0000

The same conclusion is easily confirmed by studying probabilities and F- distribution test statistics. All probabilities values are lower than 10% and t-student and F-student test statistics are greater than critical values, obtained by statistical tables of t-student and F-distributions for 10% level of significance. Durbin-Watson test statistic indicates that maybe there is a possible problem of autocorrelation due to lower values, while there is a possible existence of multicollinearity problem due to the highest values of coefficients of determination.

Finally, as we can see from the estimated results, examining the economic interrelation between dependent variables and independent ones, we can infer that alternative and nuclear energy, as well electricity production from renewable sources and exports of mineral resources have a positive effect on economic growth. The empirical results of ordinary least squares method are summarized in Table 4.

It can be inferred that an increase of energy use per 1% causes an increase of gross domestic product per 0.7, also an increase of alternative and nuclear energy per 1% causes an increase of gross domestic product per 0.91, an increase of electricity production from renewable sources per 1% causes an increase of gross domestic product per 0.38, and finally an increase of exports of mineral resources per 1% causes an increase of gross domestic product per 0.16.

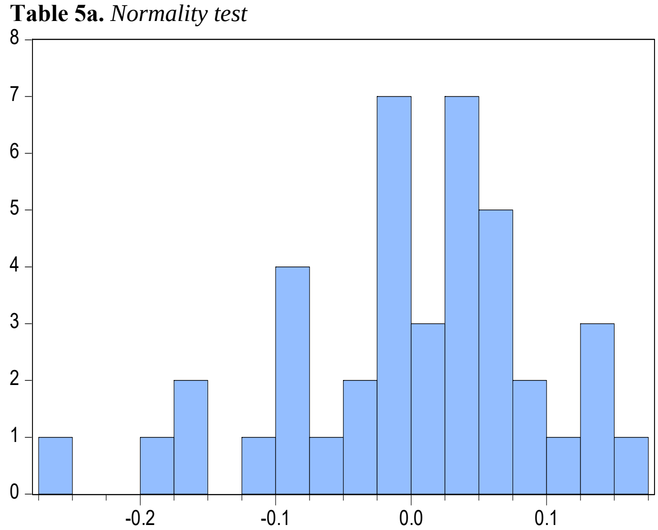
The empirical results of estimated diagnostic tests indicated that there are autocorrelation, specification and heteroscedasticity problems in residuals of estimated model due to lower values of possibilities than the relative level of significance 5%, while there isn't any problem in normality test. The empirical results of estimated diagnostic tests are presented in Table 5.

Table 5. *Diagnostics tests*

Breusch-Godfrey Serial Correlation LM Test:			
F-statistic	50.036	Prob. F(2,34)	0.0000
		Prob. Chi-Square(2)	0.0000
Ramsey RESET Test			
	Value	Df	Probability
t-statistic	4.4891	35	0.0001
F-statistic	20.152	(1, 35)	0.0001
Heteroskedasticity Test: White			
F-statistic	4.4997	Prob. F(14,26)	0.0005
Obs*R-squared	29.021	Prob. Chi-Square(14)	0.0104

The Jarque-Bera statistical test is applied for normality test of residuals of estimated model. The results of normality test are presented in Table 5a. It is obvious from the estimated results that the probabilities of Breusch-Godfrey Serial Correlation LM Test (p = 0.0000), Ramsey RESET Test(p = 0.0001), White Heteroscedasticity Test (p = 0.0005), are lower than 5% level of significance, while the probability of Jarque-Bera statistical test (0.2166) is larger than 5% level of significance.

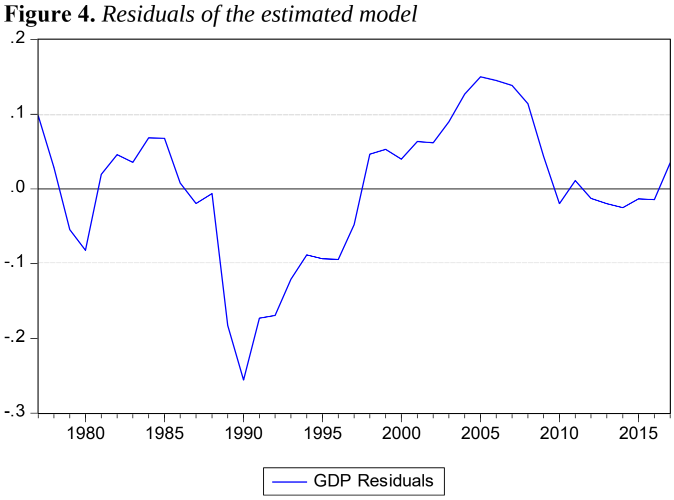
Table 5a. *Normality test*



Series: Residuals	
Sample 1977 2017	
Observations 41	
Mean	9.93e-17
Median	0.011049
Maximum	0.150164
Minimum	-0.255700
Std. Dev.	0.093943
Skewness	-0.664253
Kurtosis	3.160588
Jarque-Bera	3.059140
Probability	0.216629

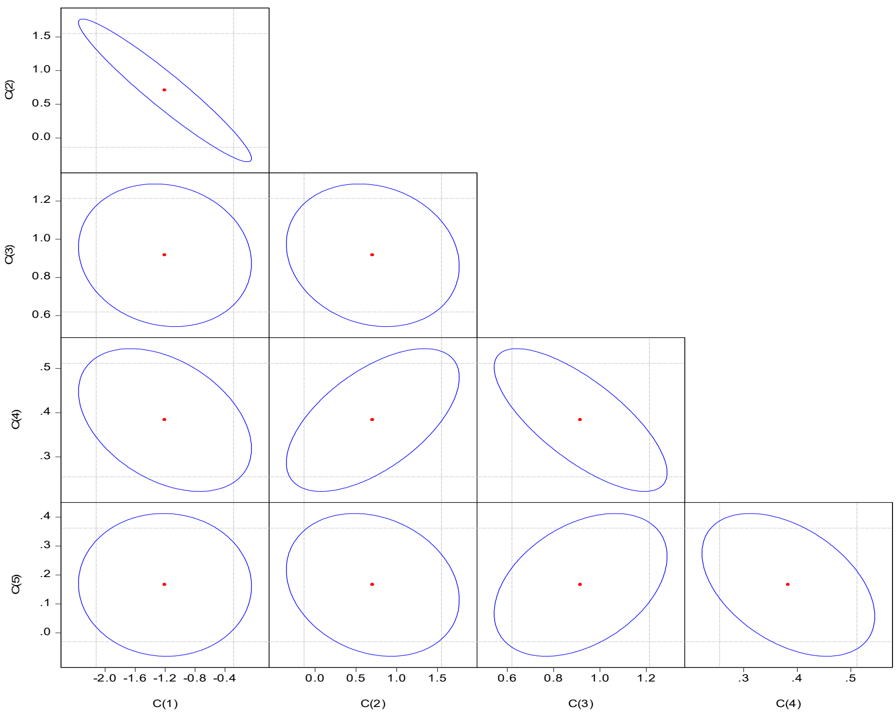
The graph of residuals of the estimated model shows that the residuals are normally distributed (Figure 4).

Figure 4. *Residuals of the estimated model*



Finally, graph of confidence ellipse of estimated coefficients of independent variables of estimated model indicates the existence of statistical significance (Figure 5).

Figure 5. *Graph of confidence ellipse of estimated coefficients*



5. Conclusions

This study investigates the interrelation between energy and economic growth for USA covering the time period from 1975 to 2017 by estimating a linear regression model with ordinary least squares method. The most important diagnostic tests are applied in order to examine the possible existence of statistical significance of the estimated equation model. The empirical results of this study are agreed with the studies of Sadorsky (2009), Apergis and Payne (2012), indicated that energy growth affects economic growth directly and positively. There isn't any problem in normality test of residuals, while there are problems in autocorrelation, specification, heteroscedasticity tests for residuals.

Summarizing, most empirical studies attempted to investigate the main determinants of economic growth emphasizing in the effects of energy sector on it. The energy consumption and the electricity production from renewable sources promote economic growth and contribute to the improvement of production and the development of standard of living. The excessive use of electric power causes an inevitable increase of pollution of environment. On the other hand the utilization of energy renewable sources declines the carbon dioxide emissions causing improvement of standard of living and quality of human life. Many empirical studies examining the main determinants of economic growth differ relatively to the sample period, the examined countries and the estimation methodology. However, more interest should be focused on the comparative analysis of empirical results for many other countries in future research.

References

Adamopoulos, A., 2019. An empirical analysis of simulated model of economic growth for United Kingdom, *Journal of Statistical and Econometric Methods*, 8(3), pp. 1-19.

Adamopoulos, A. and Kalogeridis, N., 2019. Tourism, energy and economic growth an empirical analysis, paper presented in 10th International Conference of International Business (ICIB) Thessaloniki, Greece, 2019, <https://www.icib.eu>

Apergis, N. and Payne, J., 2011. The renewable energy consumption–growth nexus in Central America, *Applied Energy,* 88(1), pp. 343-347.

Apergis, N. and Payne, J., 2012. Renewable and non-renewable energy consumption-growth nexus: Evidence from a panel error correction model, *Energy Economics,* 34(3), pp. 733-738.

Belke, A., Dobnik, F., and Dreger, C., 2011. Energy consumption and economic growth: New insights into the cointegration relationship, *Energy Economics*, 33 (5), pp. 782-789.

Breusch, T., 1978. Testing for Autocorrelation in Dynamic Linear Models, *Australian Economic Papers,* 17, pp. 334-355.

Breusch, T. and Pagan, A., 1979. A Simple Test for Heteroskedasticity and Random Coefficient Variation, *Econometrica*, 47 (5), pp. 1287-1294.

Chang, T. and Caudill, S., 2005. Financial development and economic growth: the case of Taiwan, *Applied Economics*, 37, pp. 1329-1335.

Choi, I., 1992. Effects of data aggregation on the power of the tests for a unit root, *Economics Letters*, 40, pp. 397-401.

Chontanawat, J. Hunt, L. and Pierse, R., 2008. Does energy consumption cause economic growth? Evidence from a systematic study of over 100 countries, *Journal of Policy Modeling*, 30, pp. 209-220.

Destek, M., 2016. Renewable energy consumption and economic growth in newly industrialized countries: Evidence from asymmetric causality test, *Renewable Energy*, 95, pp. 478-484.

Dickey, D. and Fuller, W., 1979. Distributions of the estimators for autoregressive time series with a unit root, *Journal of American Statistical Asso*ciation, 74, pp. 427-431.

Dritsakis, N. and Adamopoulos, A., 2004. Financial development and economic growth in Greece: an empirical investigation with Granger causality analysis, *International Economic Journal*, 18, pp. 547-559.

Durbin, J. and Watson, G., 1971. Testing for serial correlation in least squares regression.III, *Biometrika*, 58 (1), pp. 1-19.

Engle, R., 1982. Autoregressive Conditional Heteroscedasticity with Estimates of Variance of United Kingdom Inflation, *Econometrica,* 50, pp. 987-1008.

Eviews 10.0., 2017. *Quantitative Micro Software*, Irvine, California.

Godfrey, L., 1978. Testing Against General Autoregressive and Moving Average Error Models when the Regressors Include Lagged Dependent Variables, *Econometrica*, 46, pp. 1293-1301.

Hall, C., Lindenberger, D. Kümmel, R. Kroeger, T. and Eichhorn W., 2001. The need to reintegrate the natural sciences and economics, *BioScience*, 51, pp. 663-673.

Hondroyiannis, G., Lolos, S. and Papapetrou E., 2002. Energy consumption and economic growth: assessing the evidence from Greece, *Energy Economics*, 24, pp. 319-336.

Jarque, C.M. and Bera, Anil K., 1980. Efficient tests for normality, homoscedasticity and serial independence of regression residuals, *Economics Letters*, 6 (3), pp. 255-259.

Jebli, M., Youssef, S. and Ozturk, I., 2016. Testing environmental Kuznets curve hypothesis: The role of renewable and non-renewable energy consumption and trade in OECD countries, *Ecological Indicators,* 60, pp. 824-831.

Johansen, S., 1988. Statistical analysis of co-integrated vectors. *Journal of Economics Dynamics Control*, 12, pp. 231-254.

Johansen, S. and Juselious, K., 1990. Maximum Likelihood Estimation and Inference on Cointegration with Applications to the Demand for the Money, *Oxford Bulletin of Economics and Statistics,* 52, pp. 169-210.

Katos, A., 2004. *Econometrics: Theory and practice*, Thessaloniki: Zygos

Katos, A., Pekos, G., Katsouli, E. and Batzios, C., 1996. Saving-Investment Equilibrium in the European Union: An Economic Policy Exercise, *RISEC*, 43(1), pp. 81-107.

Katsouli, E., 2006. Testing the surprise consumption function: A comparative study between 15 European Union member-states, *International Research Journal of Finance and Economics*, 1, pp. 36-41.

Laopodis, N. and Sawhney, B., 2007. Dynamic interactions between investment and the stock market evidence from cointegration and error correction models, *Applied Financial Econ*omics, 17, pp. 257-269.

Lau E., Chye, X. and Choong, C., 2011. Energy-growth causality: Asian countries revisited, *International Journal of Energy Economics and Policy,* 1(4), pp. 140-149.

Osterwald-Lenum, M., 1992. A Note with quantiles of the asymptotic distribution of the maximum likelihood cointegration rank test statistics, *Oxford Bulletin Economics and Statistics*, 54, pp. 461-472.

Menegaki, A., 2011. Growth and renewable energy in Europe: A random effect model with evidence for neutrality hypothesis, *Energy Economics,* 33(2), pp. 257-263.

Phillips, P. and Perron, P., 1988. Testing for a unit root in time series regression, *Biometrika*, 75, pp. 335-346.

Ramsey, J., 1969. Tests for Specification Errors in Classical Linear Least Squares Regression Analysis, *Journal of the Royal Statistical Society*, 31(2), pp. 350-371.

Sari, R., Ewing, B. and Soytas, U., 2008. The relationship between disaggregate energy consumption and industrial production in the United States: An ARDL approach, *Energy Economics*, 30(5), pp. 2302-2313.

Schwarz, G., 1978. Estimating the dimension of a model, *Annals of Statistics*, 6, pp. 461-466.

Seddighi, H., Lawler, K. and Katos, A., 2000. *Econometrics: A practical approach,* London: Routledge.

Stern, D. and Cleveland, C., 2004. Energy and Economic Growth, *Working Papers in Economics*, Rensselaer Polytechnic Institute, Department of Economics.

Vazakidis, A., 2006. Testing simple versus Dimson market models: The case of Athens Stock Exchange, *International Research Journal of Finance and Economics*, 2, pp. 26-34.

White, H., 1980. A Heteroskedasticity-Consistent Covariance Matrix Estimator and a Direct Test for Heteroskedasticity, *Econometrica*, 48 (4), pp. 817-838.

World Development Indicators Statistical database, <https://data.worldbank.org>