IJEEP
INTERNATIONAL JOURNAL OF ENERGY ECONOMICS AND POLICY
EJ EconJournals
ISSN: 2146-4553

International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2019, 9(6), 193-198.

EJ EconJournals

Comparison of Nuclear Energy and Renewable Energy Consumption in terms of Energy Efficiency: An Analysis on the EU Members and Candidates†

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Received: 16 March 2019 **Accepted:** 24 August 2019 **DOI:** https://doi.org/10.32479/ijeep.7866

ABSTRACT

Energy efficiency is one of the main dynamics of sustainable development. As energy is used efficiently, the energy need for economic growth will be reduced, and the costs of energy sources will be reduced. In this context, nuclear and renewable energy are compared in terms of energy efficiency. The data of the energy efficiency index of 13 countries and the data on nuclear energy and renewable energy consumption over the years 1995-2016 and the dynamic ordinary least squares and fully modified ordinary least squares tests are performed. As a result of the analysis, it is determined that there is a long-term relationship between the variables and that both energy sources have a positive effect on energy efficiency, but renewable energy is more advantageous than nuclear energy in terms of energy efficiency.

Keywords: Nuclear Energy, Renewable Energy, Energy Efficiency, Cointegration
JEL Classifications: C33, O13, Q42, Q47

1. INTRODUCTION

One of the main dynamics of sustainable economic growth and development for countries involves having sufficient energy sources. The economic crisis that began with the rise of energy costs in the 1970s revealed the importance of energy for sustainable economic growth. Within this process, especially along with the decline of fossil fuel reserves, nuclear energy, and renewable energy sources have emerged as alternative energy sources. The reduction in fossil fuel reserves, the energy-related crises, and the emergence of alternative energy sources have revealed the necessity of efficient energy usage. The official statistics agency of the European Union has also been publishing the energy efficiency index since 1995, drawing attention to the concept of energy efficiency. Energy efficiency index measures the amount of economic output produced per unit of the gross domestic energy consumption. Brookes (1990), Saunders (1992) and Inhaber and Saunders (1994) claimed that efficient use of energy was effective on economic growth. Brookes (1990), Saunders (1992) and Inhaber and Saunders (1994) stated that improvements in energy efficiency would have led to rapid growth.

Although no research study comparing nuclear energy and renewable energy in terms of efficiency has been witnessed, there have been several studies comparing economic, ecological, and other aspects. Upon summarizing the studies which compare the impacts of energy sources on carbon emission, the study of Apergis et al. (2010) is seen as one of the studies conducted in this context. In the study, nuclear energy and renewable energy consumption were compared in terms of carbon emissions. As a result of the

† The summary of manuscript was orally presented in Turkish within the scope of the 5th ICPESS Symposium.

analysis using data obtained from 19 developed and developing countries, it was asserted that nuclear energy consumption played a crucial role in reducing carbon emissions in the short-run, whereas renewable energy consumption did not contribute to carbon emission reduction. Similar results were obtained in Menyah and Wolde-Rufael (2010), which was conducted in the USA.

Baek (2016), also conducted on the USA, stated that nuclear energy consumption reduced carbon emissions both in the short- and the long-run, whereas renewable energy consumption reduced carbon emissions only in the short-run. Similarly, Doğan and Ozturk (2017), conducted in the USA, claimed that renewable energy consumption reduced carbon emissions, whereas non-renewable energy (including nuclear energy) consumption increased carbon emissions. In Dong et al. (2018) conducted on China, the impacts of renewable energy, and nuclear energy consumptions on carbon emissions were tested comparatively. Contrary to the former studies, it was stated that the reduction impact of nuclear energy consumption on carbon emissions was lower than that of renewable energy. As a more comprehensive study, Vo et al. (2019) tested the role of renewable energy and nuclear energy in reducing carbon emissions comparatively. As a result of the study which utilized the data of nine pacific countries, both energy sources were found to be effective in reducing carbon emissions, but according to country-specific factors, it was determined that renewable energy in some countries and nuclear power consumption in some other countries reduced carbon emissions even more. Upon evaluation of the studies comparing nuclear energy and renewable energy in terms of economic contribution, Lee (2012) is considered as one of the formerly conducted studies. In the study, it is intended to answer the question of whether renewable energy sources or nuclear energy sources were more advantageous for hydrogen production. As a result of the study, renewable energy sources were detected as more advantageous for hydrogen production.

In another study, Mbarek et al. (2015), the relationship between renewable energy, nuclear energy, and economic growth in France was analyzed. As a result of the performed analysis, nuclear energy was identified as an indispensable energy source for France, and it was stated that renewable energy could not be an alternative to nuclear energy and could only be a complementary energy source. Park et al. (2016) compared the production costs of renewable energy, nuclear energy, and fossil fuels in Korea. In the study, nuclear energy was determined as more advantageous in terms of production costs. As a result of the analysis performed on nine developed countries in Saidi and Mbarek (2016), no causal relationship between nuclear energy consumption and economic growth could be determined, but a bilateral causal relationship between renewable energy consumption and economic growth was detected. In the study of Mbarek et al. (2018), which had similar results, the relationships of nuclear energy and renewable energy with gross domestic product (GDP) were investigated. As a result of the study in which the data obtained from 18 developed and developing countries were used, a causal relationship was detected from GDP towards renewable energy consumption, whereas no causal relationship was found between GDP and nuclear energy consumption. Ozturk (2017) examines the impact of alternative and nuclear energyconsumption (NE), fossil fuel energy consumption (FFUEL), carbon dioxide emissions (CO_2) and oil rent (OILRENT) on economic growth (GDPPC) and foreign direct investment (FDI) in the panel of nine Latin American countries, for the period of 1975-2013. The result of pooled seemingly unrelated regression (SUR) indicates the importance of NE, FFUEL and CO_2 emissions that positively contributed to increasing GDP per capita, while oil rents fail to promote economic growth in the region. Similar results have been obtained with the FDI in which the role of energy sources amplified the foreign investment on the cost of CO_2 emissions in the region.

Upon evaluating the studies comparing nuclear energy and renewable energy both economically and ecologically, Hong et al. (2018), one of the studies in this context, evaluated the possible economic and environmental impacts of nuclear energy sources in case they were replaced with renewable energy sources in Sweden. As a result of the performed analysis, it was stated that replacing nuclear energy with renewable energy sources would have contributed positively to neither the economy nor the environment. In the study of Cebulla and Jacobson (2018), who drew different conclusions, simulation of the possible advantages and disadvantages in terms of cost and carbon emissions in the coming years was performed in case of the replacement of nuclear energy sources with renewable energy sources such as wind turbines. Consequently, it was stated that both cost advantages would be achieved and carbon emissions would be reduced if nuclear energy sources were to be replaced with wind turbines. In the study of Jin and Kim (2018), who drew similar conclusions, nuclear and renewable energy were compared in terms of both economic and ecological aspects. Utilizing the data of 30 countries, it was asserted that renewable energy use and expansion of such use were more economical and ecologically beneficial.

The conducted studies in the literature indicate that energy consumption and energy efficiency have a positive and significant impact on economic growth. Therefore, it is crucial for countries to use energy sources efficiently. This study aims to compare nuclear energy consumption and renewable energy consumption in terms of energy efficiency via econometric methods.

2. DATA AND METHODOLOGY

In this study, energy consumption, renewable energy consumption and energy efficiency index data (at annual frequency and in natural logarithm) obtained from 13 countries (Germany, Belgium, Bulgaria, Czech Republic, Finland, France, the Netherlands, England, Spain, Sweden, Hungary, Slovenia and Slovakia) which are the members of the European Union and the potential candidates are used. The study period is determined between these dates since more countries can be analyzed during the relevant dates. The relevant data are obtained from the official website of the European Union, namely, Eurostat (2018) (https://ec.europa.eu/eurostat/web/energy/data/database).

In this study, firstly, Levin, Lin and Chu and Im, Pesaran and Shin tests and unit root tests are performed to determine whether or not the data are stationary. After determining whether or not data are suitable for analysis; panel cointegration, fully modified

Table 1: Descriptive statistics

Variables	Mean	Standard error	Minimum	Maximum	Observations
lnEnProd	1.6084	0.4850	0.1823	2.3979	286
lnNuclear	8.9985	1.2558	6.4317	11.6654	
lnRenew	8.1581	1.2326	6.0186	10.5692	

ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS) analyses and Emirmahmutoğlu and Köse (2011) panel causality analysis are performed.

Levin et al. (2002) and Im et al. (2003) unit root tests are used to determine whether or not the variables used in the analysis are stationary. Nelson and Plosser (1982) asserted that statistical methods could not be used in the evaluation of studies conducted with non-stationary time-series. The variables must be stationary in order to perform the panel causality analysis. Upon performing panel unit root tests, first or second-generation unit root tests are preferred depending on whether or not the series to be used are related to each other. As some of the first generation unit root tests used in this study, Levin et al. (2002) is preferred on the assumption of the homogeneous model, whereas Im et al. (2003) is preferred on the assumption of the heterogeneous model.

Cointegration analysis is conducted to test the long-term relationship between the variables. The cointegration tests developed by Pedroni (1999) and Kao (1999) are among the most commonly used cointegration tests in empirical analyses. Pedroni test is based on error terms derived from the regression model. The short-run adjustment process for the variables in their differences is required to be equal to the long-run cointegrating vector for the variables in their levels (Westerlund, 2007: 710). The basic assumption of Pedroni (1999) cointegration test is that there is no cross-sectional dependence between the variables. Under this assumption, the null hypothesis (of no cointegration for the panel cointegration test) is tested with seven different panel cointegration test statistics, four of which are based on "within" dimension and three of which are based on "between" dimension. In the cointegration tests proposed in Pedroni (1999), the first stage involves the estimation of the residuals obtained from the cointegration regression expressed in Equation (1) (Pedroni, 1999. p. 656).

$$y_{i,t} = \alpha_i + \delta_i t + \beta_{1i} x_{1i,t} + \beta_{2i} x_{2i,t} + \ldots + \beta_{Mi} x_{Mi,t} + \varepsilon_{i,t} \quad (1)$$

$t = 1,2,\ldots,M$; $i = 1,2,\ldots,N$; $m = 1,2,\ldots,M$

α denotes the fixed-effect parameter, δ denotes the deterministic time trend, β denotes the slope coefficients, t denotes the number of observations, i denotes the cross-sections, and m denotes the number of variables.

In the Pedroni cointegration analysis, the existence of cointegration between the variables y and x is tested by the stability analysis conducted for $\varepsilon_{i,t}$ error terms. The test developed by Kao (1999) is based on the panel regression model expressed in Equation (2).

$$y_{i,t} = x'_{it}\beta + z'_{it}\gamma + \varepsilon_{it} \quad (2)$$

Table 2: Panel unit root tests

Variables	Levin, Lin and Chu		Im, Pesaran and Shin	
	Constant	Constant and trend	Constant	Constant and trend
lnEnProd	0.0981	−2.8369*	3.9938	−4.3473*
ΔlnEnProd	−14.1060*	−10.1242*	−13.1383*	−9.5317*
lnNuclear	−1.3988	−1.8471**	−1.9966**	−1.8547**
ΔlnNuclear	−15.5522*	−14.3972*	−15.1372*	−14.3971*
lnRenew	−0.8380	−2.4278*	3.2246	−2.2537**
ΔlnRenew	−15.6323*	−12.8625*	−14.1505*	−11.3344*

*Indicates significance at 1% and **at 5% levels of significance, respectively

The cointegration test is developed by applying to the Augmented Dickey-Fuller (ADF) and Dickey-Fuller (DF) stationary tests conducted for the error terms in the relevant model. The Kao (1999) cointegration test, based on the ADF and DF stationarity analyses, is performed with five different test statistics on the null hypothesis, assuming that there is no cointegration relationship between the variables.

The most commonly used methods for estimating the cointegration coefficients include the DOLS developed by Saikkonen (1991) and Stock and Watson (1993) and the FMOLS estimators developed in Phillips and Hansen (1990). Pedroni (2001) contributed to the use of estimators in panel data. As a parametric approach, the DOLS method is an approach that corrects autocorrelation by including the lagged first differences into the model. Panel DOLS estimator is expressed as follows (Breitung and Pesaran, 2008. p. 310):

$$y_{it} = \beta' x_{it} + \sum\nolimits_{k=-\infty}^{\infty} \gamma'_k x_{it-k} + \mu_{it} \quad (3)$$

y_{it}: Dependent variable, x_{it}: Independent variable, β: The cointegration vector, μ: The error term.

Unlike the DOLS method, the FMOLS method is a nonparametric approach. The FMOLS method takes into account the existence of a possible relationship among the fixed term, the error term, and the differences of the independent variables. Panel FMOLS estimator is as follows (Narayan and Wong, 2009. p. 2774):

$$y_{it} = \alpha_{it} + \beta x_{it} + \varepsilon_{it} \quad (4)$$

$$x_{it} = x_{i,t-1} + \varepsilon_{it} \quad (5)$$

Emirmahmutoğlu and Köse (2011) causality analysis, being the adapted version of Toda and Yamamato (1995) to the panel and using the meta-analysis developed by Fisher (1932), is performed even if the variables are not stationary at the same level. Another advantage of this test involves taking the cross-sectional dependence into consideration and its usability even if the cointegration relationship cannot be determined (Emirmahmutoğlu and Köse, 2011). Since the test also has a heterogeneous structure,

Table 3: Pedroni and Kao cointegration test results

Pedroni panel cointegration test results				
	$lnEnProd = \alpha_{it} + \beta lnNuclear_{it} + \beta lnYRenew_{it} + \mu_{it}$			
	t - statistics	Probability	Weighted t - statistics	Probability
Panel v-Statistic	1.3213	0.0932	1.0016	0.1583
Panel rho-Statistic	−1.0625	0.1440	−1.3639	0.0863
Panel PP-Statistic	−2.9978*	0.0014	−3.1650*	0.0008
Panel ADF-Statistic	−3.4969*	0.0002	−3.8646*	0.0001
		t-statistics		Probability
(Between-dimension)				
Group rho-Statistic		−0.2039		0.4192
Group PP-Statistic		−3.2415*		0.0006
Group ADF-Statistic		−4.5838*		0.0000
Kao panel cointegration test results				
ADF		−1.7931*		0.0365

*Significant at 1% level of significance

it can provide results for both the panel and for each cross-section (Kurt and Köse, 2017: 306). In this test, the Equations (3) and (4), which indicate causality relationships based on two-variable VAR model can be established as follows (Emirmahmutoğlu and Köse, 2011. p. 872):

$$x_{i,t} = \mu_i^x + \sum_{j=1}^{k_i+dmax_i} A_{11,ij} x_{i,t-j} + \sum_{j=1}^{k_i+dmax_i} A_{12,ij} y_{i,t-j} + \mu_{i,t}^x \quad (6)$$

$$y_{i,t} = \mu_i^y + \sum_{j=1}^{k_i+dmax_i} A_{21,ij} x_{i,t-j} + \sum_{j=1}^{k_i+dmax_i} A_{22,ij} y_{i,t-j} + \mu_{i,t}^y \quad (7)$$

$i = 1, 2,\ldots,N$ and $j = 1, 2,\ldots, k$

x_i and y_i denote the variables, μ_i denotes the error term, A denotes the fixed-effect matrix, k_i denotes the lags, $dmax_i$ denotes the maximum integration value for each cross-section, i denotes the cross-sections, and t denotes the periods of time.

3. FINDINGS

Nuclear energy consumption, renewable energy consumption, and energy efficiency index data are analyzed in the natural logarithm. The descriptive statistics of the relevant data, both in the raw data state and in the natural logarithm, are presented in Table 1.

Upon evaluating the descriptive statistics presented in Table 1, it is seen that the volatility in nuclear energy consumption is higher than the volatility in renewable energy consumption. The lowest volatility among the variables is found in the energy efficiency index. Levin, Lin and Chu and Im, Pesaran and Shin unit root tests are performed to determine whether or not the data of the relevant variables are stationary. The test results are given in Table 2.

Upon evaluating the unit root test results, it is determined that the variables that contain unit roots at the level, whereas the difference series does not contain unit roots, in other words, the series is stationary. According to these results, the cointegration test between variables and the causality analysis in the difference series can be realized. In Table 3, the results of Pedroni and Kao cointegration tests indicating the cointegration relationship between variables are presented.

Table 4: DOLS and FMOLS test results

$lnEnProd = \alpha_{it} + \beta lnNuclear_{it} + \beta lnRenew_{it} + \mu_{it}$		
	Coefficient	t-statistics
DOLS test results		
Renewable energy consumption	0.2649	2.4868**
Nuclear energy consumption	0.1364	15.8961*
FMOLS test results		
Renewable energy consumption	0.2509	4.2243*
Nuclear energy consumption	0.1527	25.6571*

*Significant at 1% level of significance

The results of both cointegration tests in Table 3 indicate that energy efficiency, nuclear energy consumption, and renewable energy consumption are co-integrated, in other words, there is a balanced relationship between variables in the long-run. The results of the DOLS and FMOLS tests conducted to determine the direction of the relationship between the variables are given in Table 4.

Upon evaluation of the DOLS and FMOLS test results, it is determined that both nuclear energy consumption and renewable energy consumption have positive and significant impacts on energy efficiency. Upon comparison of both energy sources, it can be said that renewable energy consumption is more efficient in terms of energy efficiency than nuclear energy consumption. The results of Emirmahmutoğlu and Köse (2011) causality test, which is conducted for detecting the causality from both renewable energy and nuclear energy consumptions towards energy efficiency, are given in Table 5.

According to Emirmahmutoğlu and Köse (2011) causality test results, it is determined that the causality running from nuclear energy towards energy efficiency is valid for Bulgaria, France, Netherlands, Sweden, and UK, whereas the causality towards renewable energy consumption and energy efficiency is valid for Bulgaria, Slovenia and Spain.

4. CONCLUSION AND SUGGESTIONS

Energy is one of the basic requirements for economic growth in terms of countries. Because economic growth is required to ensure production. Besides the basic raw materials, production

Table 5: Emirmahmutoğlu and Köse (2011) causality test results

Countries	Nuclear energy⇒Energy efficiency			Renewable energy⇒Energy efficiency		
	Lag	Wald	P-value	Lag	Wald	P-value
Belgium	2	0.014	0.993	4	4.227	0.376
Bulgaria	1	2.699***	0.099	3	7.751***	0.051
Czech Republic	1	1.266	0.261	1	0.324	0.569
Finland	4	5.740	0.219	1	1.118	0.290
France	1	3.753***	0.053	1	0.322	0.570
Germany	1	1.121	0.290	1	1.228	0.268
Hungary	1	2.595	0.107	1	0.269	0.604
Netherlands	1	5.468**	0.019	1	1.012	0.315
Slovakia	1	0.459	0.498	1	0.763	0.382
Slovenia	1	0.179	0.672	1	3.370***	0.066
Spain	3	2.865	0.413	2	11.547*	0.003
Sweden	1	9.911*	0.002	1	0.360	0.549
UK	1	8.779*	0.003	1	0.175	0.676

*Indicates significance at 1%, **at 5%, ***at 10% levels of significance, respectively

growth requires the energy that would be used by the technology to produce such raw materials. In this context, energy is one of the vital elements of economic growth. Therefore, countries are in pursuit of new energy sources in order to meet their energy needs while trying to develop projects that would enable efficient use of existing energy sources. Energy efficiency can be evaluated in two aspects. The first involves the production of more energy to be used at the same cost, and the second involves the production of more economic output by consuming the same amount of energy.

This study aims the comparison of nuclear energy and renewable energy in terms of energy efficiency. Both cointegration analysis and DOLS and FMOLS tests are applied to the data obtained from 13 EU member and candidate countries. Upon evaluation of the results, in general, it can be stated that both nuclear energy and renewable energy have positive impacts on energy efficiency. The nuclear energy sources meet the expectations due to their high energy capacity and potential based on the economies of scale. Renewable energy sources, however, provide a significant cost advantage using natural raw materials, except for the first investment costs. It also offers an advantage in terms of efficiency. The results suggesting that renewable energy consumption is more advantageous compared to nuclear energy consumption comply with the results of Mbarek et al. (2015) and Park et al. (2016) studies while Cebulla and Jacobson (2018), Dong et al. (2018) and Jin and Kim (2018).

Moreover, being relatively more environment-friendly, it provides an important advantage by lowering environmental pollution costs. Although both energy sources are perceived as mutual alternatives, in fact, they are complementary to each other. It is almost impossible to meet these needs with a single energy source in today's world in which energy needs tend to increase constantly. In this respect, it can be suggested that each country should invest in both energy sources in line with its own circumstances and that more investments should be made in renewable energy sources in terms of efficiency.

The analysis is conducted only for a few countries. It can be stated that the inclusion of more country data into the analysis and usage of different methods in the future studies would contribute to the literature in terms of the generalization of the results. Furthermore, new studies examining the relationship between the energy efficiency index and other different financial and economic data are expected to provide different contributions to the subject.

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