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Relationship between Renewable Energy and Economic Growth in Developed Countries

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ABSTRACT

In this study, the relationship between renewable energy and economic growth in G7 countries for the period 2000-2023 was investigated with Kao and Johansen Fisher panel cointegration tests and the direction of the relationship was determined with the FMOLS and DOLS test results. The empirical findings obtained show that there is a positive relationship between renewable energy production and economic growth. According to the results of the FMOLS method application, a 1% change in renewable energy production in G7 countries will cause approximately 0.70% change in economic growth in the long term. As a result of the DOLS method application, this coefficient was estimated as 0.66.

Keywords: Renewable Energy, Economic Growth, G7 Countries, Panel Data Analysis
JEL Classifications: Q42, O40, C32

1. INTRODUCTION

The fact that oil is an indispensable source of input in many sectors is important for the progress of the economic process (Syzdykova and Azretbergenova, 2024). There are two basic problems in accessing energy today. First, fossil resources are limited. Even if there is no problem with supply today, there will definitely be a problem 1 day. Therefore, alternative energy sources must be investigated. The second is the global climate change problem. The intense accumulation of CO_2 gas in the atmosphere causes global warming (Apergis and Danuletiu, 2014). Global warming and climate change problems have taken the relationship between economic growth, energy demand and environmental pollution to a new dimension. It was decided to reduce the amount of greenhouse gas emissions within the framework of the Kyoto Protocol. As a result, many countries have started to increase the use of renewable energy sources by reducing the use of fossil fuels. When it comes to renewable energy sources, the first sources that come to mind are usually the energy obtained from solar, wind, geothermal and biomass sources. Unlike traditional energy sources, renewable energy sources are clean, reliable and inexhaustible. Therefore, their use is rapidly increasing on a global scale because the most important feature of renewable energy sources is that they help protect the environment by reducing CO_2 gas emissions, positively affect basic macroeconomic indicators such as employment and foreign trade balance by reducing dependency on foreign energy sources, and ensure energy supply security (Lund, 2009).

In the literature, the effects of energy use on the economy are discussed as an important issue. It is seen that these discussions mostly focus on the relationship between energy consumption and economic growth (Syzdykova et al. 2020; Syzdykova et al. 2022). In recent years, the energy sources used have diversified as a result of the decreasing costs with the developing renewable energy technologies. This situation has led to the distinction between non-renewable and renewable energy use in studies on energy. In fact, this distinction has been made more specific and has led to the investigation of the effects of the use of hydraulic, solar, wind, geothermal and biomass resources on the economy. This study aims to investigate the relationship between renewable energy consumption and economic growth in the G7 countries. For this purpose, first of all, the studies conducted in the past will be summarized in terms of the results obtained, then the relationship between renewable energy consumption and economic growth variables in the G7 countries will be investigated with Kao and Johansen Fisher panel cointegration tests and the direction of the relationship will be determined with the FMOLS and DOLS test results.

2. LITERATURE REVIEW

Some of the studies investigating the relationship between renewable energy and economic growth for a single country can be summarized in terms of the country examined and the results achieved. In their studies on Lithuania by Bobinaite et al. (2011); India by Tiwari (2011); Iran by Khoshnevis Yazdi and Shakouri (2017); and Malaysia by Haseeb et al. (2019), they determined that there is a one-way causality from renewable energy consumption to economic growth. Azad et al. (2014) concluded in their studies for Australia and Burakov and Freidin (2017) for Russia that there is a one-way causality relationship from economic growth to renewable energy consumption. In their studies conducted by Pao and Fu (2013) for Brazil; Lin and Moubarak (2014) for China; Cherni and Jouini (2017) for Tunisia; and Rafindadi and Öztürk (2017) for Germany, they found that there is a bidirectional causality between renewable energy consumption and economic growth. Bowden and Payne (2010) examined the relationship between renewable energy consumption and economic growth for the US economy by sector. In the study, a one-way causality relationship was found from renewable energy consumption to economic growth in the residential sector, while no causality relationship was found between commercial and industrial renewable energy consumption and economic growth. Tugcu et al. (2012) have shown in their study examining G7 countries one by one that the causality relationship between renewable energy consumption and economic growth can be one-way or reciprocal, as well as meaningless. It is possible to say that the differences in empirical results are based on the specific characteristics and internal dynamics of the countries rather than the differences in the period and econometric method examined.

The relationship between renewable energy and economic growth has also been the subject of panel analyses in recent years. Apergis and Payne (2010a) for 20 OECD countries; Apergis and Payne (2010b) for 13 Eurasian countries; Apergis and Payne (2011a) for 6 Central American countries; Apergis and Payne (2012) for 80 countries; Apergis and Danuletiu (2014) for 80 countries determined that there is a mutual causality relationship between economic growth and renewable energy consumption. Bhattacharya et al. (2016) found a unidirectional causality from renewable energy consumption to economic growth in the 38 countries that consume the most renewable energy, and Inglesi-Lotz (2016) found a unidirectional causality from renewable energy consumption to economic growth in the 34 OECD countries. Menegaki (2011) concluded that there is no causality relationship between renewable energy consumption and economic growth in his study examining 27 European countries. Apergis and Payne (2011b) stated that there is a unidirectional causality from economic growth to electricity consumption from renewable resources in the short term and a reciprocal causality in the long term, according to the results of their analysis for 16 developing market economies.

Apergis and Danuletiu (2014) analyzed the relationship between renewable energy and economic growth using panel data analysis method and Canning-Pedroni causality test for 80 developed and developing countries. In the study using annual data for the period 1990-2012, it was concluded that renewable energy consumption is important for economic growth and there is a causality relationship from economic growth to renewable energy consumption.

Kula (2014) investigated whether there is a long-term relationship between per capita renewable energy consumption and economic growth in 19 OECD countries for the period 1980-2008 by using the dynamic panel data method. The analysis results showed that there is a long-term relationship between the variables and the direction of the relationship is from economic growth to renewable energy consumption.

Salim et al. (2014) investigated the relationship between renewable and non-renewable energy sources, industrial production and economic growth for 29 OECD countries in the period 1980-2011. In the study where panel data analysis was used, it was determined that there was a long-term relationship between the variables in question. The causality test results showed that there was a bi-directional causality relationship between renewable and non-renewable energy consumption and industrial production in both the short and long term, and a uni-directional causality relationship between economic growth and renewable and non-renewable energy consumption in the short term.

Shahbaz et al. (2015) investigated the relationship between renewable energy consumption and economic growth for Pakistan using the ARDL method and vector error correction model. The analysis results using the data for the period 1972:1-2011:4 showed that the variables are cointegrated in the long run, renewable energy consumption increases economic growth and there is a bidirectional causality between them.

Bhattacharya et al. (2016) studied the impact of renewable energy consumption on economic growth in 38 countries with the largest renewable energy consumption in the world for the period 1991-2012. The results of the heterogeneous panel data analysis showed that renewable energy consumption has a positive effect on economic growth.

Inglesi-Lotz (2016) examined the long-term relationship between renewable energy consumption and economic growth for 34 developed and developing OECD countries in the period 1990-2010 using the panel data method and concluded that there is a significant and positive relationship between renewable energy consumption and economic growth.

Armeanu et al. (2017) revealed that there is a one-way causality from economic growth to renewable energy production for 28 EU countries. When the results obtained in the prominent panel analyses in the literature are evaluated, it is seen that the studies stating that there is a two-way causality relationship between renewable energy consumption and economic growth are predominant.

Rafindadi and Öztük (2017) examined the effect of renewable energy consumption on economic growth in Germany for the period 1971:1-2013:4 using the ARDL bounds test and the Bayer-Hanck cointegration test. The results obtained from the analysis showed that renewable energy consumption increased economic growth in the examined period and that there was a bidirectional causality relationship between the variables in question. Syzdykova et al. (2021) found that renewable energy consumption had a positive effect on economic growth for selected developing countries (Brazil, India, Indonesia, China, Chile, Mexico, South Africa and Turkey).

As can be seen, no common conclusion has been reached in the studies examining the relationship between renewable energy consumption and economic growth due to the differences in the methods used, the selected sample group and the time periods examined.

3. DATA SET AND ECONOMETRIC METHOD

The long-term relationship between renewable energy production and economic growth was examined in the study using data from G7 countries between 2000-2023. Renewable energy production data were obtained from the official website of the OECD, and gross domestic product data, which represents economic size, was obtained from the official website of the World Bank. The data were used in the analysis by taking their natural logarithms. G7 countries consist of Germany, the United States, the United Kingdom, Italy, France, Japan and Canada. Table 1 explains the symbols and definitions of the variables and the sources from which they were taken.

In the study, firstly, in order to examine the long-term relationship between renewable energy production (*REP*) and economic growth (*EG*), cross-section dependency and homogeneity tests were applied for the countries included in the panel data set. The stationarity of the series was examined with ADF and PP Fisher unit root tests. After obtaining the stationary series, the relationship between renewable energy production and economic growth was investigated with Kao and Johansen Fisher panel cointegration tests and the direction of the relationship was determined with the FMOLS and DOLS test results. The mathematical form of the econometric model to be studied is expressed as follows:

$$EG_{it} = \alpha_{it} + \beta_{it} REP_{it} + u_{it}$$

In the model $i = 1,2,3.,7$; and $t = 1,2,3.23$. The *EG* variable in the model represents "annual growth values of gross domestic product", *REP* represents "renewable energy production," and u represents the error term.

4. ANALYSIS OF FINDINGS

4.1. Cross-Section Dependency and Homogeneity Tests

In order to make a choice between the first and second generation cointegration tests in the study, the existence of inter-unit correlation needs to be tested. In case of inter-unit correlation (cross-section dependency) between error terms, since the first generation cointegration tests will be weak, second generation cointegration tests are needed. The results of Breusch and Pagan (1980) LM test, Pesaran (2004) CD Test and Pesaran et al. (2008) NLM test are shown in Table 2 below.

According to the results of Breusch and Pagan (1980) LM test and Pesaran et al. (2008) NLM test, H_0 hypothesis was rejected and it was concluded that there was a correlation between the units. According to Pesaran (2004) CD Test, which gave better results than Breusch and Pagan (1980) LM test when $T > N$, H_0 hypothesis could not be rejected and it was determined that there was no correlation between the units. Since the data set used in the study consisted of 7 cross-sections and 23 periods, in other words, since $T > N$, it was accepted that there was no correlation between the units according to Pesaran (2004) CD Test and first generation cointegration tests were used.

4.2. Panel Unit Root Tests

In this study, five different panel unit root tests, namely Levin et al. (2002), Breitung (2000), Im et al. (2003), ADF and PP Fisher type unit root tests, were applied to the renewable energy production series and economic growth series of the G7 countries for the period 2000-2023, as joint and individual unit root tests. The results are presented in Tables 3 and 4.

As can be understood from Table 3, renewable energy production series are stationary at the level only in the fixed model in the Levin, Lin and Chu test and in the fixed-trend model in the PP-Fisher type test. According to all other tests and models, it was observed that the series were not stationary at the level. When Table 3 was examined, it was observed that the series were stationary at the 1% significance level in the fixed and fixed-trend models in the 1st differences according to 5 different unit root tests. Therefore, renewable energy production series were used in the analyses with their 1st differences.

As can be seen from Table 4, EG series are stationary according

Table 1: Definition of variables

Variable	Definition	Source
REP	Renewable energy production	OECD
EG	Gross domestic product annual% growth	World bank

Table 2: Cross-section dependency tests

Test	Statistics	Probability
Breusch and Pagan (1980) LM test	620.8	0.0000
Pesaran et al. (2008) NLM test	49.83	0.0000
Pesaran (2004) CD Test	0.601	0.8062

to the constant model in ADF-Fisher type test, Im, Pesaran and Shin test and Levin, Lin and Chu test, but they are not stationary according to the constant-trend model. EG series are stationary at level only in the constant model in Levin, Lin and Chu test and in the constant-trend model in PP-Fisher type test. It was observed that the series are not stationary at level according to all other tests and models. For this reason, GDP series were also used in the analyses with their 1st differences.

4.3. Panel Cointegration Tests

After obtaining stationary series by applying unit root tests, a study was conducted using the Kao and Johansen Fisher cointegration test to determine whether there is a long-term relationship between renewable energy production and economic growth. In Kao's (1999) cointegration test, heterogeneity is also accepted among the cointegration vectors, but the rule of endogeneity of independent variables is violated due to asymptotic equivalence. Table 5 shows the Kao and Johansen Fisher Panel cointegration test results.

When the Kao cointegration test results were examined; the hypothesis H_0: There is no cointegration between the series" was rejected at a significance level of 10%. According to the Johansen Fisher cointegration test, the H_0 hypothesis was rejected and the alternative hypothesis "H_0: There is cointegration between the series" was accepted. According to the Kao Panel cointegration Test and the Johansen Fisher Panel cointegration test, a long-term relationship was found between the variables.

4.4. FMOLS-DOLS Tests and Analysis

After cointegration tests are applied, Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS), developed by Pedroni (2000) to estimate the long-term relationship between renewable energy production and economic growth, are applied to calculate the final unbiased coefficient with an asymptotic distribution that allows for a large degree of heterogeneity in the short term.

While conducting the current relationship research between variables in the dynamic panel with the FMOLS method, the constant term, the error term and the correlation degree that allows heterogeneity between the variables are taken into account. In this direction, the FMOLS method developed is based on the panel regression model shown below:

$$y_{it} = \alpha_i + \beta x_{it} + u_{it}$$

$$x_{it} = x_{it-1} + x^{\varepsilon}_{it}$$

In the equation, Y_{it} represents the dependent variable, χ_{it} represents the independent variable and αi represents the fixed effects. However, the sections forming the panel have an asymptotic distribution. In equation (2), where the long-term cointegration relationship between the dependent variable (y_{it}) and the independent variable x_{it} is shown, the long-term cointegration coefficient indicated by β will be estimated. Another method

Table 3: Unit root tests for the *REP* variable

Method	Level		1st difference	
	Intercept	Intercept and trend	Intercept	Intercept and trend
Levin, Lin and Chu t	−2.077 (0.018)**	0.093 (0.5332)	−4.081 (0.000)*	−4.647 (0.000)*
Breitung t-stat	-	2.734 (0.996)	-	−2.737 (0.003)*
Im, Pesaran and Shin W-stat	3.316 (0.888)	1.325 (0.911)	−4.649 (0.000)*	−4.616 (0.000)*
ADF-Fisher Chi-square	28.258 (0.875)	34.129 (0.6492)	103.041 (0.000)*	84.681 (0.000)*
PP-Fisher Chi-square	23.123 (0.806)	95.929 (0.000)*	242.929 (0.000)*	267.271 (0.000)*

Probability values are in parentheses. *, ** and ***indicate 1%, 5% and 10% statistical significance levels, respectively

Table 4: Unit root tests for the *EG* variable

Method	Level		1st difference	
	Intercept	Intercept and trend	Intercept	Intercept and trend
Levin, Lin and Chu t*	−5.525 (0.000)*	0.912 (0.779)	−7.114 (0.000)*	−12.454 (0.000)*
Breitung t-stat	-	2.690 (0.962)	-	2.664 (0.006)*
Im, Pesaran and Shin W-stat	−3.115 (0.009)*	2.832 (0.873)	−4.547 (0.000)*	−6.805 (0.000)*
ADF-Fisher Chi-square	55.050 (0.004)*	24.707 (0.888)	83.816 (0.000)*	130.326 (0.000)*
PP-Fisher Chi-square	41.305 (0.353)	7.635 (1.000)	100.663 (0.000)*	182.880 (0.000)*

Probability values are in parentheses. *İndicate 1% statistical significance level

Table 5: Kao Panel cointegration test results

Tests	t-Statistics	Probability value
ADF	1.360171	0.0604***
Residual variance	0.006071	
HAC variance	0.008003	

Johansen Fisher Panel Cointegration Test Results				
Calculated VE (s) numbers	Fisher statistics (from trace test)	Probability value	Fisher statistics (from max-eigen test)	Probability value
None	80.14	0.0000*	60.88	0.0121**
Maximum 1	79.73	0.0000*	79.73	0.0000*

*, **and ***denote 1%, 5% and 10% statistical significance levels, respectively

Table 6: FMOLS and DOLS tests

Variables	Coefficients	t-Statistics
FMOLS	0.7044	4.3581*
DOLS	0.6631	3.0279*

*indicate 1% statistical significance level

developed by Pedroni (2001) to estimate the final unbiased coefficients of the relationship between renewable energy production and economic growth is the DOLS method. The DOLS method gives more consistent results in small samples. For this reason, the DOLS method was also used in the study when estimating the long-term cointegration coefficients. The regression equation used in the DOLS group average panel estimator method is as follows:

$$EG_{it} = \alpha_i + \beta_i REP_{it} + \sum_{k=-Kiyik}^{K_i} \Delta REP_{it-k} + u_{it}$$

The group average panel DOLS estimator generated from the above equation is represented by the following equation:

$$\hat{\beta}^{*}_{GD} = N^{-1}\sum_{i=1}^{N} \hat{\beta}^{*}_{D,i}$$

The matrix represented by t* in the equation above shows the cointegration coefficient obtained from the DOLS estimation for each cross-section. The t-statistics of the group average panel DOLS estimators are calculated using the following equation:

$$t\hat{\beta}^{*}_{GD} = \left(\hat{\beta}^{*}_{D,i} - \beta_0\right)\left[\hat{\sigma}_i^{-2}\sum_{t=1}^{T}(REP_{it} - \overline{REP}_l)^2\right]^{1/2}$$

As seen in Table 6, according to the results of the FMOLS method application developed by Pedroni (2000), the coefficient is estimated as 0.70. The result shown in Table 6 is positive and statistically significant at the 1% significance level. In this case, a 1% change in renewable energy production in G7 countries will cause approximately 0.70% change in economic growth in the long term.

As a result of the application of the DOLS method developed by Pedroni (2001), this coefficient was estimated as 0.66. The estimated result is positive and statistically significant at the 1% significance level. According to these findings, as in the FMOLS test results, a 1% change in renewable energy production in the G7 countries in general will cause approximately 0.66% change in economic growth in the long term. According to these results, the positive results of both FMOLS and DOLS coefficients indicate that there is a positive relationship between renewable energy production and economic growth in the long term in the G7 countries, in other words, renewable energy production positively affects economic growth.

5. CONCLUSION

Energy has a central position in terms of healthy execution of vital activities and ensuring economic development. It does not seem possible for countries that cannot solve the energy problem to achieve their economic goals and establish their social balance. Although countries meet their energy needs with two different tools, renewable and non-renewable energy sources, the unbalanced distribution of non-renewable energy sources in the world, the high supply cost for countries that do not have these resources and the limited fossil fuel reserves make renewable energy both necessary and mandatory. In this study, the causal relationship between renewable energy consumption and economic growth was analyzed with data for the period 2000-2023 for the G7 countries. The findings show that there is a positive long-term relationship between renewable energy and economic growth. According to the results of the FMOLS method application, a 1% change in renewable energy production in G7 countries will cause approximately 0.70% change in economic growth in the long term. As a result of the DOLS method application, this coefficient is estimated as 0.66. Investments in renewable energy and the positive externalities that these investments will create will significantly support economic growth and development by increasing domestic production, creating more employment and reducing import bills. Therefore, it is very important for countries to turn to new and renewable energy sources, prioritize the production of technologies that can mobilize these sources, increase energy efficiency and reduce energy intensity in order to achieve their medium and long-term goals.

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