CHAPTER 9

The Relationship Between Renewable Energy Consumption and Economic Growth in Selected Developed and Developing Economies

Asst. Prof. Dr. Cebrail Telek[1]

1. Introduction

Energy, a very important concept since the existence of man, is defined as the ability of a system to do work. With the increased use of machines in production as a result of the industrial revolution, the energy demand has increased, even more, making energy even more important to humans. Today, it is one of the most important factors that countries need to achieve sustainable economic growth and development. From this point of view, it can be said that the amount of energy produced and consumed by countries is one of

1 Adıyaman University, FEAS, Department of Economics, ADIYAMAN, ctelek@adiyaman.edu.tr, ORCID: 0000-0002-4541-3402

the most important indicators of their level of development. For this reason, countries that want to increase their level of prosperity make great efforts to produce, extract and consume energy.

Historically, it is known that people first used energy to radiate heat and rays, to heat and warm, and that they usually obtained this energy from firewood. It can be said that as economies develop and become more complex, their energy needs increase dramatically. As the resulting supply of fuelwood and other biomass energy proved insufficient to power growing economies such as Europe and the United States, people used hydropower in the nineteenth century, then coal, oil, and natural gas in the twentieth century, and nuclear power in the 1950s (Timmons et al ., 2014: 3). As the supply of fossil fuels (oil, natural gas, coal, etc.), referred to as non-renewable energy sources, declines, countries are turning to alternative energy sources to meet their energy needs (Hubbert, 1956: 19-20).

As can be seen, the energy that people need can be obtained from many different sources. From this point of view, energy resources can be classified in different ways. According to these classifications, energy resources are divided into renewable and non-renewable energy resources depending on their use. Non-renewable (exhaustible) energy sources are fossil sources (coal, oil, natural gas) and nuclear sources (uranium, thorium); renewable (inexhaustible) energy sources are water, solar, biomass, wind, geothermal, wave, tidal, and hydrogen (Koç and Şenel, 2013: 33). People have accelerated the search for renewable energy sources because non-renewable energy sources are exhausted and their supply is decreasing, costs are increasing, and the natural environment and living beings are being harmed. Renewable energy sources are particularly environmentally friendly because they are a repeatable and inexhaustible source of energy, which increases their importance. The main subject of this study is the impact of the use of renewable energy sources on the welfare level of countries.

We can define economic growth as the increase in the number of goods and services produced in a country in a given period of time. Economic growth is the continuous increase in real GDP over time. Economic growth is the only way to increase the standard of living and the level of welfare of the people living in a country. For this reason, one of the most important macroeconomic goals of countries is undoubtedly economic growth (Uensal, 2009: 14-15). For this reason, countries try to achieve economic growth by using non-renewable energy resources even though they harm the natural environment and living beings. However, with the recent increase in environmental awareness, countries are turning to renewable energy as an alternative to fossil fuels.

The objective of the study is to examine the relationship between renewable energy consumption and economic growth in developed and developing countries. For this purpose, the United States, Germany, France, the United Kingdom, and Japan were selected as developed countries; for developing countries, data from Turkey, China, Russia, Brazil, and Argentina were sampled for the period 1990-2018. In studying the impact of renewable energy consumption on economic growth, separate panel data were created to compare developed and developing countries. CADF and CIPS unit root tests from the second generation of panel data analysis, Westerlund cointegration test for long-run relationships, and DOLSMG and FMOLS estimators for coefficient estimation were used as the method. Following the introductory section of the study, a literature review of previous studies on this topic is provided. Then, the empirical methods used in the study are explained and the results obtained through the analyzes are interpreted. Finally, a general assessment of the study was made and recommendations were made.

2. Literature Review

The rapid growth of the world's population and the energy needs of the developing industrial sector are increasing substantially.

Meeting this energy demand with non-renewable traditional energy sources increasingly endangers the natural environment and human health. For this reason, the extraction and use of renewable energy sources that are compatible with nature are of great importance. The relationship between renewable energy consumption in individual countries and their economic growth has been a focus of interest in the literature in the context of recent environmental problems.

Menegaki (2011) examined the causal relationship between economic growth and renewable energy for 27 European countries in a multivariate panel over the period 1997-2007. Although panel causality tests show short-term relationships between renewable energy and GHG emissions and employment, the experimental results do not confirm causality between renewable energy consumption and GDP. The estimated cointegration factor shows only a weak correlation between economic growth and renewable energy consumption in Europe.

Sebri and Salha (2014), on the other hand, examine the causal relationship between economic growth and renewable energy consumption in BRICS countries over the period 1971-2010 in a multivariate framework. The methods used were the ARDL bound test approach and the Vector Error Correction Model (VECM). The results of the analysis show that there is a bidirectional causal relationship between economic growth and renewable energy consumption. This explains the role of renewable energy in promoting economic growth in BRICS countries.

In another study examining OECD countries, Salim et al. (2014) examine the dynamic relationship between renewable and nonrenewable energy consumption, industrial production, and GDP growth using data for the period 1980-2011. The method used was the Westerlund panel cointegration test and the Granger causality test, which allow for structural breaks. The results show that there is a long-term cointegration relationship between non-

renewable and renewable energy sources, industrial production, and economic growth. Panel causality analyzes show bidirectional causality between industrial production and renewable and nonrenewable energy consumption in the short and long run. However, there is evidence of a bidirectional short-run relationship between GDP growth and non-renewable energy consumption, while there is unidirectional causality between GDP growth and renewable energy consumption.

Jebli and Youssef (2015) use panel cointegration techniques to examine the causal relationship between production, consumption of renewable and non-renewable energy, and international trade for a sample of 69 countries over the period 1980-2010. In the short run, Granger causality tests show bidirectional causality between production and trade (exports or imports), bidirectional causality between non-renewable energy and trade, and unidirectional causality between renewable energy and trade. At the same time, our long-term projections from OLS, FMOLS, and DOLS show that renewable and non-renewable energy consumption and trade have a positive and statistically significant impact on economic growth.

Özşahin et al. (2016) investigated the relationship between renewable energy consumption and economic development using data for BRICS countries and Turkey for the period 2000-2013. The existence of a long-run relationship between the variables was investigated by Pedroni (1999) and Westerlund (2005) using the panel CUSUM cointegration test, and the long-run coefficients were obtained using the panel ARDL estimator. The empirical results show that there is a long-run positive relationship between renewable energy consumption and economic development.

Kılıç and Aslan (2016) studied the impact of renewable and nonrenewable energy consumption on economic growth for the period 1990-2013 for 28 OECD countries. Johansen-Fischer and Pedroni cointegration tests and Granger causality tests were

used as methods. At the same time, the coefficients of the long-run cointegration relationship were estimated using the Pedroni FMOLS method. The results of the analysis show that there is a long-run cointegration relationship between the variables. For the long-run FMOLS coefficients, it was found that some countries are negatively affected by non-renewable energy, but the use of renewable energy contributes to the economic growth of all 28 OECD countries.

İzgi and Destek (2017) studied the impact of renewable and non-renewable energy consumption on economic growth in BRICS and MIST countries for the period 1992-2014, using the Kao cointegration test, panel FMOLS, and DH panel causality test of Dumitrescu and Hurlin (2012) as methods. The results show that there is a cointegration relationship between the variables in the long run. The results of FMOLS coefficients suggest that both renewable energy consumption and non-renewable energy consumption have a positive effect on the economic growth of the whole panel, but in comparison, non-renewable energy consumption was more effective for economic growth. According to the results of the panel causality test, unidirectional causality holds between economic growth and renewable energy consumption, and a bidirectional causal relationship was found between non-renewable energy consumption and economic growth.

In his study, Ito (2017) empirically investigated the relationship between CO2 emissions, renewable, and non-renewable energy consumption, and economic growth using panel data from 42 developed countries during the period 2002-2011. The method used was the difference-GMM estimator proposed by Arellano and Bond (1991) and the PMG estimator based on the autoregressive distributed lag (ARDL) model introduced by Pesaran et al. for a dynamic panel model with lagged dependent variables. The results show that non-renewable energy consumption has a negative impact on the economic growth of developing countries. Moreover, it is

found that renewable energy consumption contributes positively to economic growth in the long run.

In another study, Akdağ and İskenderoğlu (2018) examined the relationship between economic growth and consumption of nonrenewable energy, renewable energy, and nuclear energy. Dynamic panel difference between 2007-2016 of 14 countries (Germany, Belgium, Bulgaria, Czech Republic, Finland, France, Netherlands, England, Spain, Sweden, Hungary, Romania, Slovakia, and Slovenia) in the EU member and candidate countries. The system was tested with GMM data analysis. The results of the analysis show that non-renewable and renewable energy consumption has a positive and significant impact on GDP, while nuclear energy consumption has no significant impact. It can be seen that the influence of renewable energy consumption on GDP is higher than the other variables in both the difference GMM and system GMM methods. This result shows that it is necessary to implement policies in which each country should focus more on renewable energy consumption to achieve higher growth.

Alper (2018) in his study examined the relationship between renewable energy consumption and economic growth in Turkey using the Bayer-Hanck cointegration test and Toda-Yamamoto causality tests for the period 1990-2017. The results show that there is a cointegration relationship between the variables in the long run and that a 1% increase in renewable energy consumption increases economic growth by 0.19%. However, a unidirectional causality relationship was found from economic growth to renewable energy use.

Singh et al. (2019) studied 20 developed and developing countries for the period 1995-2016 using the FMOLS method. The empirical results show that renewable energy has a positive and statistically significant effect on economic growth. The results also show that the impact of renewable energy generation

on economic growth is higher in developing countries than in developed countries.

Rahman and Velayutham (2020) examine the relationship between renewable and non-renewable energy consumption and economic growth for a panel of five South Asian countries (Bangladesh, India, Nepal, Pakistan, and Srilanka) during 1990-2014. The study used Pedroni's (1999, 2004) and Kao's (1999) cointegration tests and Dumitrescue-Hurlin's (2012) panel causality test as methodology. The results showed positive effects of renewable and non-renewable energy consumption and fixed investment on economic growth. Renewable energy consumption, non-renewable energy consumption, and a 1% increase in capital increase economic growth by 0.66%, 0.10%, and 0.58%, respectively. Moreover, it has been shown that there is a unidirectional causality between economic growth and renewable energy consumption.

Ünüvar and Keskinkılıç (2020) investigated the relationship between renewable energy production and economic growth for 19 G20 member countries during 2000-2016 using Kao and Johansen Fisher Panel cointegration, FMOLS, and DOLS tests as methods. The empirical results show that there is a positive relationship between renewable energy production and economic growth.

In another similar study, Ivanovski et al. (2021) examined the impact of renewable and nonrenewable energy consumption on economic growth. A nonparametric modeling technique was used to identify 39 countries for the period 1990-2015, considering OECD countries and other countries as two different models. Dynamic CCEMG and non-parametric LLDVE panel data tests were used. The results show that non-renewable energy consumption has a positive and significant impact on economic growth in all OECD countries. However, the impact of renewable energy consumption on economic growth is statistically non-

zero during most of the time in these countries. Renewable and non-renewable energy consumption promotes economic growth in non-OECD countries, suggesting that developing countries can play an important role in the transition to renewable energy despite the limitations of technological progress.

Asiedu et al. (2021) examine the relationship between renewable and nonrenewable energy consumption, CO2 emissions, and economic growth in 26 European countries over the period 1990-2018. Panel cointegration techniques developed by Kao (1999) and Pedroni (1995) were used to test for the presence of cointegration between variables, and DOLS and FMOLS methods developed by Pedroni (2004), as well as Granger causality tests, were used to determine the long-run flexibility between variables. The results of the analysis show that there is a long-term relationship between nonrenewable and renewable energy, carbon monoxide, and economic growth. There is bidirectional causality between economic growth and renewable energy consumption and a unidirectional causality between renewable energy and non-renewable energy consumption and between renewable energy and CO2 emissions.

There are numerous studies in the literature that examine the relationship between renewable energy consumption and economic growth. The studies differ in terms of the countries/country groups studied, the time period, and the methods used. This study differs from other studies by including actual data in the analysis using different methods and by comparing the groups of developed and developing countries, so it is considered to contribute to the literature.

3. Data, Model, Method, and Empirical Findings

In this part of the study, the data set, models, and methods used in the analysis are explained, and the empirical findings obtained from the analyzes are interpreted.

3.1. Data, Model, and Method

The purpose of this study is to examine the relationship between countries' economic growth levels and the amount of renewable energy they consume, as well as the potential impact of renewable energy consumption on growth. To examine this relationship, the United States, Germany, France, the United Kingdom, and Japan were used as developed countries; two different groups of countries, China, Russia, Turkey, Brazil, and Argentina, were included in the analysis as developing countries.

Economic growth and renewable energy consumption data are from the World Bank's database, World Development Indicators. The time period of the study was 1990-2018, and 29 years of data were used.

In examining the impact of renewable energy on growth, a panel for developed countries and a separate panel for developing countries were created to compare impacts in developed and developing countries.

The study first tested cross-sectional dependence. Second-generation tests are used to continue the analysis in series with cross-sectional dependence. Since there is a problem of cross-sectional dependence between variables, the stationarity of the variables was tested using the CADF and CIPS unit root tests, which are second-generation unit root tests. The presence of a cointegration relationship between the variables was examined using the Westerlund cointegration test. The cointegration model for the variables is as follows:

$$GDP_{it}=\beta_0+ \beta_1 RE_{it} + \varepsilon_{i,t}$$

In the equation, *GDP* represents the growth rates of the countries, *RE* represents the amount of renewable energy in the countries, and ε represents the error term. For the coefficient estimator model built to determine the direction of the relationship between the variables, the homogeneity status was first checked using the

Swamy-S homogeneity test. Since the panel is heterogeneous, the DOLSMG and FMOLS estimators were used.

3.2. Empirical Findings

Pesaran's (2004) CD test was applied to determine the cross-sectional dependence between the variables. The cross-section dependency test result is shown in Table 1.

Table 1. Cross-Section Dependency Test

	Panel		GDP		logRE	
	Developed	**Developing**	**Developed**	**Developing**	**Developed**	**Developing**
CD-Test	9.045	4.199	9.36	4.22	13.68	6.79
P-Value	0.0000	0.0000	0.000	0.000	0.000	0.000

As can be seen in Table 1, the fact that the probability values based on the panel or the variables are less than 5% for both developed and developing countries indicates that there is cross-sectional dependence between the panel and the variables. In this case, the analysis continues with second-generation tests.

CADF and CIPS unit root tests were applied to investigate the stationarity of the variables. The test results obtained are shown in Table 2 below.

Table 2. Unit Root Test Results

CADF					
			Critical Values		
	Developed	**Developing**	**%1**	**%5**	**%10**
GDP	-4.153	-2.369	-2.570	-2.330	-2.210
logRE	-1.516	-2.354			
CIPS					
			Critical Values		
Panel	-1.504	-2.625	-2.57	-2.33	-2.21

According to the results of the CADF unit root test, since the t-bar value of the GDP variable is larger than the absolute value of the critical values for developed countries, this variable does not have a unit root, that is, it is stationary at the level, while the t-bar value of the logRE variable is smaller than the absolute value of the critical values. It was found that the level is not stationary. In developing countries, both GDP and logRE variables are stationary at the 5% and 10% significance levels but have a unit root at the 1% significance level, i.e., they are non-stationary. Looking at the panel in general with the CIPS unit root test, the developed countries are nonstationary at the level, while the developing countries are stationary at the level.

The homogeneity of the slope coefficients of the variables was measured with the S test developed by Swamy. The test results obtained are shown in Table 3.

Table 3. Swamy S Homogeneity Test

	Chi-Square Value		p-value		Result	
	Developed	**Developing**	**Developed**	**Developing**	**Developed**	**Developing**
Model (Co. Vari.: FDI)	14.66	120.54	0.0661	0.0000	Heterogeneous at 10%.	Heterogeneous at 1%.

The fact that the probability value in the Swamy S homogeneity test is below 5% indicates that a change in the variable RE can have a different effect on the variable GDP, i.e. the model is heterogeneous.

The presence of a long-term cointegration relationship between variables was tested using Westerlund cointegration analysis. The test results obtained are presented in Table 4.

Table 4. Westerlund Cointegration Test Results

	Constant				Constant ve Trend			
GDP	Statistic		p-value		Statistic		p-value	
	Developed	**Developing**	**Developed**	**Developing**	**Developed**	**Developing**	**Developed**	**Developing**
G_t	-4.089	-2.682	0.000 ***	0.010 **	-3.802	-3.220	0.000 ***	0.040 **
G_a	-16.497	-12.461	0.000 ***	0.000 ***	-14.737	-13.543	0.040 **	0.060 *
P_t	-9.054	-5.830	0.000 ***	0.040 **	-8.816	-6.450	0.000 ***	0.100
P_a	-17.368	-11.194	0.000 ***	0.000 ***	-15.864	-12.137	0.010 **	0.080 *

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

The fact that the probability values in both developed and developing countries are in part 1% and in part less than 5% shows that there is a cointegrated relationship between the variables in the long run in both the fixed and trend models (table 4).

The results of the DOLSMG and FMOLS coefficient estimator tests applied to determine the direction of this relationship after the cointegration relationship was determined are shown in Table 5.

Table 5. DOLSMG and FMOLS Coefficient Estimators Results

Developed Countries							
Dependent: GDP		**DOLSMG**		**FMOLS**			
		Coefficient	**p-value**	**Coefficient**	**Std. Error**	**p-value**	
Independent logRE	Panel	0.7308	0.6612 **	1.770818	0.431751	0.0001 ***	
	USA	4.474	1.98				
	Germany	1.723	1.788 **				
	France	0.4265	0.3827 **				
	UK	-1.066	-1.499 **				
	Japan	-1.903	-1.174 **				
Developing Countries							
Dependent: GDP		**DOLSMG**		**FMOLS**			
		Coefficient	**p-value**	**Coefficient**	**Std. Error**	**p-value**	
Independent logRE	Panel	-0.02784	-0.1818 **	2.511863	0.696592	0.0004 ***	
	Chinese	9.75	1.847 **				
	Turkey	3.29	0.1919 **				
	Brazil	-6.953	-1.136 **				
	Russia	31.68	0.9233 **				
	Argentina	-37.9	-2.232				

******, **, * denote 1%, 5% and 10% significance levels, respectively. For the FMOLS test, Schwarz criterion for lag length and pooled panel method were considered. The table value of t is 1.96 for α=0.05.***

According to the results of the DOLSMG coefficient estimator for developed countries, it can be said that renewable energy consumption has an impact on economic growth in the whole panel. A one-unit increase in renewable energy consumption increases economic growth by 0.73%. While a one-unit increase in renewable energy consumption increases growth by 1.72% in Germany and 0.42% in France, it decreases growth by 1.06% in the United Kingdom and 1.9% in Japan. It can be said that renewable energy consumption in the United States does not affect economic growth. According to the results of the FMOLS coefficient estimator, renewable energy consumption affects economic growth in the whole panel. A one-unit increase in renewable energy consumption increases growth by 1.77% in the entire panel.

According to the results of the DOLSMG coefficient estimator, we can say that renewable energy consumption has a negative effect on economic growth in the whole panel. A one-unit increase in renewable energy consumption in the whole panel increases economic growth by 9.75%, 3.29% in Turkey, and 31.68% in Russia. In Brazil, a one-unit increase in renewable energy consumption reduces growth by 6.95%. In Argentina, renewable energy consumption does not affect economic growth. According to the results of the FMOLS coefficient estimator, renewable energy consumption affects economic growth in the entire panel. A one-unit increase in renewable energy consumption increases economic growth by 2.51%.

4. Conclusion

Today, it is important for countries to achieve sustainable and healthy economic growth in order to raise people's living standards and welfare levels. Undoubtedly, energy has a large part in the ability of countries to achieve this. Countries that do not have sufficient energy for their economic growth cannot achieve their economic goals. To achieve sufficient energy supply, countries

resort to many methods. Some of these methods include non-renewable (exhaustible) energy resources such as fossil sources (coal, oil, natural gas) and nuclear fuels (uranium, thorium); renewable (inexhaustible) energy sources such as water, solar, biomass, wind, geothermal, wave, tidal, and hydrogen.

The energy that people need to continue their lives and increase their level of prosperity can be obtained from many different sources. However, it is well known that non-renewable sources of energy are being depleted and their supply is decreasing due to increasing costs and the degradation of the natural environment and living beings. For these reasons, people have recently been pushing the search for and using renewable energy sources. Since renewable energy sources are a repeatable and inexhaustible source of energy that is less harmful to the environment, their importance is increasing.

The objective of the study is to examine the potential impact of renewable energy consumption in individual countries on their economic growth. To see the difference between developed and developing countries, the United States, Germany, France, the United Kingdom, and Japan are considered developed countries; developing countries, Turkey, China, Russia, Brazil, and Argentina are included in the analysis. To compare 1990-2018 data with those of developed and developing countries, separate panels were created and analyzes were conducted using the CADF and CIPS unit root tests, the Westerlund cointegration test for long-term relationships, and the DOLSMG and FMOLS estimator methods for the coefficient estimates.

With the Westerlund cointegration test, a long-term cointegration relationship was determined between the renewable energy consumption of countries and their economic growth. According to the results of DOLSMG and FMOLS coefficient estimators in both developed and developing countries, it can be said that renewable energy consumption is effective on economic

growth throughout the panel. In developed countries, a 1 unit increase in renewable energy consumption across the panel increased economic growth by 0.73%; in developing countries, it increases by 9.75%. This finding reveals how important the use of renewable energy is for developing economies. For this reason, it is very important for countries to increase their use of renewable energy in order to achieve sustainable economic growth. In addition, it can be said that renewable energy is very important for a sustainable world in terms of contributing to the economic growth of countries as well as causing less harm to the natural environment and living things. For this reason, it can be recommended that countries or policymakers turn towards the production and use of renewable energy and transfer their resources and technologies to this field.

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