



Analysis of the Relationship Between Renewable Energy and Economic Growth in Selected Developing Countries

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ABSTRACT

Whether there is a relationship between economic growth and energy consumption and the direction of this relationship is of great importance in energy policy decision making in countries where the state plays an active role in energy markets. If there is a relationship from energy to growth, conservative policies such as energy taxes, energy-saving, and energy prices will hurt growth. There are many studies in the literature investigating the effects of renewable and non-renewable energy consumption on the economic growth of countries. Since different data, periods, and methods were used in the studies, consensus could not be achieved. Therefore, this issue remains current and continues to be investigated. The main purpose of this study is to determine whether renewable energy consumption has a positive effect on economic growth for selected developing countries (Brazil, India, Indonesia, China, Chile, Mexico, South Africa and Turkey). Fossil energy consumption and CO₂ emissions variables are also included in the model established for this purpose. GMM estimator, one of the dynamic panel data methods, was used for empirical analysis of the relationship between these variables.

Keywords: Renewable Energy Consumption, Carbon Emission, Economic Growth, Dynamic Panel Data, GMM Method

JEL Classifications: O40, Q43, Q40

1. INTRODUCTION

The global energy market is constantly evolving and increasing its importance. Today, the main problems of the global energy market are the country's becoming foreign-dependent with increasing energy demand, energy supply security and the transportation of energy safely, market domination of fossil fuels, and global climate change. Developing countries are countries that suffer from these problems. Because they have to deal with other economic problems while realizing their economic growth targets. Regarding energy, developing countries are the countries that should use scarce resources most efficiently. These countries, where the reflection of imported energy prices are seen as inflation, go through difficult processes while realizing their economic policy objectives.

Although renewable energy systems seem like an option in this regard, the problem of high funding needs is another important element that arises here. However, there is a rapid growth in investments in renewable energy in the world. Investments in industries with a \$155.4 billion investment in 2008 reached \$301.7 billion in 2019 (REN21, 2020: 31). In 2012, 16% of the world's energy consumption is met with renewable energy production, while in 2020, 26% is met.

Economies of developing, developed and underdeveloped countries in the world have basic macro economic targets throughout their economic processes. Energy policies have an important place in the policies developed to reach these goals. The main objective of this study is to analyze the relationship between

the share and quantity of renewable energy used in the supply of energy needs and the size of the country. Studies in the literature investigating the relationship in question were used in different country/country groups, models and variables (Apergis and Payne, 2010; 2011; 2012; Pao and Fu, 2013; Destek, 2016; Chen et al., 2019; Mahmood et al., 2019; Ozcan and Ozturk, 2019; Rahman and Velayutham, 2020). Developing countries are economies that continue their economic development processes in terms of structure and face many problems in this process. These countries, which are in a sensitive balance in their economic policies and energy strategies, make their decisions by considering many data and parameters. Increasing energy use and the possibility of depletion of the dominant energy sources that will meet this feature highlight renewable energy. In this study, the importance of renewable energy systems for developing countries is emphasized. For this purpose, in the empirical part of the study, the effects of renewable energy on the growth of selected developing countries (Brazil, India, Indonesia, China, Chile, Mexico, South Africa and Turkey) were analyzed using Dynamic panel data models. Country data covers 1990-2019.

The study consists of 4 chapters and empirical studies are included in the following section. In the third section, the variables and method used in the study are explained. In the fourth section, the findings of the analysis have been evaluated. The study ended with the conclusion.

2. GLOBAL RENEWABLE ENERGY CONSUMPTION

Wind, hydraulic, solar, biomass, and geothermal energy sources are made significant use of renewable energy sources around the world. According to the “2020 Renewable Energy Global Status Report” published by REN21, the share of renewable energy sources in electricity generation has risen to 26%, while it stands at 10% in the heating and cooling sectors and 3% in transportation. To solve the global climate change problem, renewable energy sources must be used in different sectors and fossil fuel consumption must be terminated (REN21, 2020:19-25).

On the other hand, the superiority of non-renewable energy sources led by fossil fuels in global electricity generation continues. To reduce this advantage, it is very important to encourage renewable energy types, especially in terms of installation costs and price competition. Technological advances, financial developments, and new market opportunities have a decreasing effect on electricity production by using renewable energy sources, primarily wind and solar (photovoltaic). Especially the use of wind and solar energy in the coastal regions becomes competitive with fossil fuels even without calculating externalities. Wind energy, for example, is considered one of the most cost-effective options in terms of grid-based energy in many countries such as Australia, Brazil, Canada, China, Mexico, New Zealand, South Africa, Turkey, and the United States.

The investments in the field of renewable energy in 2018-2019 and the total installed power capacities are given in Table 1. According to this, it is observed that the energy source with the maximum installed power capacity is hydrological sources. In 2019, China took first place in hydroelectric capacity addition, while Brazil took second place, with these countries adding more than 1GW of capacity. Wind energy has entered a rapid growth phase in the world in the 2000s. China, the United States, Germany, Spain, and India have 70% of the total installed power of World wind power. Geothermal resource utilization rate increase was mostly realized in Turkey, Indonesia, and USA countries also saw some gains. Geothermal energy is a type of energy source that continues to grow and shows optimistic development where power capacity is mostly formed in Turkey and Indonesia. Turkey and Indonesia, which make up two-thirds of the new capacities established, are the two countries that have made great contributions to development.

As in the whole of energy, more developing countries are investing in renewable energy sources. Thus, global investment in renewable energy sources is increasing. Most of the countries that lack fossil resources, such as the United States, China, Japan, and India, and that are trying to meet their needs by importing energy from outside, are making significant investments in renewable energy. In 2019, renewable energy resource investment took the lead in developing countries and left the developed countries behind. As a result, annual investment, capacity additions, and production in

Table 1: Renewable energy indicators

Renewable energy types		2018	2019	Top 5 countries in the world with the addition of investment and additional capacity in 2019				
				1	2	3	4	5
Investment								
New investment (annual) in renewable power and fuels	billion USD	296.0	301.7	China	USA	Japan	India	Chinese Taipei
Power capacity								
Renewable power (including hydropower)	GW	2.387	2.588	-				
Renewable power (not including hydropower)	GW	1.252	1.437	-				
Hydropower	GW	1.135	1.150	Brazil	China	Lao PDR	Bhutan	Tajikistan
Wind power	GW	591	651	China	USA	UK	India	Spain
Solar PV	GW	512	627	China	USA	India	Japan	Vietnam
Bio-power	GW	131	139	Indonesia	UK	Brazil	Germany	France
Geothermal power	GW	13.2	13.9	Turkey	Indonesia	Kenya	Costa Rica	Japan
Concentrating solar thermal power (CSP)	GW	5.6	6.2	Israel	China	South Africa	Kuwait	France
Ocean power	GW	0.5	0.5	-	-	-	-	-

Source: REN 21, 2020

2019; China ranks first in terms of PV solar, wind energy capacity, and solar water heating capacity. Biodiesel capacity in Indonesia, geothermal power capacity in Turkey, while in Brazil hydroelectric capacity is located in the first row.

Considering the countries in the study, Brazil is the country with the highest share of renewable energy in the total energy consumed by developing countries (Figure 1). The share of renewable energy in total energy consumption in Brazil is 45% in 2019. It is observed that the share of renewable energy in total energy consumption in all countries decreased in 2019 compared to 1990. However, this is explained by the increase in total energy consumption due to the rapid growth of these countries.

On the other hand, while the rate of carbon emissions decreased in Mexico, Brazil, Chile, and Turkey in 2019, it increased in China, India, Indonesia, and South Africa (Table 2). China alone is responsible for 28.8% of the world's carbon emissions. China constitutes 18% of the world's population and 16% of the world economy, generates 20% of the world's energy resources, and consumes 24%. China meets 58% of total energy consumption from coal.

3. LITERATURE REVIEW

The question of the sustainability of energy and the economic growth targets of the countries and the fact of climate change has

led the researchers to carry out many studies on this subject. When the previous studies are examined, an increase has been observed in the number of works within the scope of economic growth and renewable energy consumption. These studies are indicative of the importance of countries' growth in renewable energy sources in terms of development and economic growth. Also, one-way and two-way causality studies were found between economic growth and renewable energy sources. Apergis and Payne are researchers who have contributed much to the literature. They examined the relationship between renewable energy use and economic growth for OECD countries (2010a), Eurasian countries (2010b), South American countries (2010), emerging markets (2011a), Central American countries (2011) and 80 selected countries (2012). In Table 3, some studies investigating the relationship between economic growth and renewable energy consumption are summarized.

4. DATA SET AND METHOD

4.1. Data Set and Model

The study explores the relationship between renewable-non-renewable energy sources and economic growth through a panel data set created from data from 8 developing countries (Brazil, India, Indonesia, China, Chile, Mexico, South Africa and Turkey) in the world's largest economies during the period 1990-2019, which grew rapidly and generated large amounts of energy demand. The variables used in the model are shown in Table 4.

Figure 1: Renewable energy consumption in developing countries (% of total)

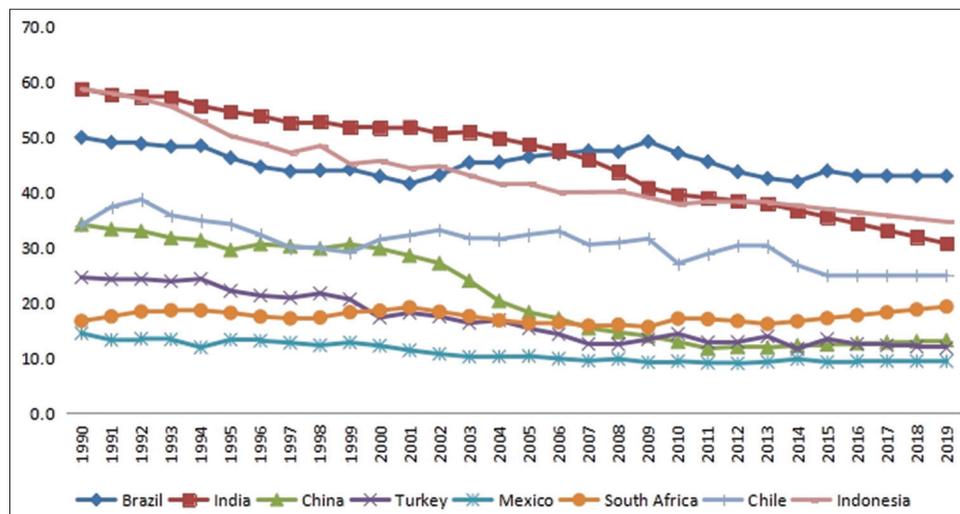


Table 2: CO₂ emissions from developing countries (million tonnes)

Countries	2017	2018	2019	Growth rate per annum (%)		Share (%)
				2019	2008-18	2019
Mexico	476.9	466.6	455.0	-2.48	0.8	1.3
Brazil	457.2	442.3	441.3	-0.21	1.7	1.3
Chile	92.4	94.3	92.4	-2.03	2.0	0.3
Turkey	397.1	392.1	383.3	-2.24	3.6	1.1
China	9298.0	9507.1	9825.8	3.35	2.6	28.8
India	2329.8	2452.5	2480.4	1.13	5.3	7.3
Indonesia	527.0	580.7	632.1	8.84	4.4	1.8
South Africa	465.8	470.4	478.8	1.8	-0.1	1.4
Total World	33279.5	34007.9	34169.0	0.5	1.1	100

Source: BP, 2020

Table 3: Summary of empirical studies

Author	Country	Period	Method	Results
Chien and Hu (2008)	116 countries	2003	Structural Equation Model (SEM)	While there is a direct relationship between the use of renewable energy resources and capital knowledge, there is no significant and direct relationship with GDP
Fang (2011)	China	1978-2008	OLS model estimator	It is determined that real GDP and per capita real GDP increase as renewable energy consumption increases
Tiwari (2011)	India	1960-2009	Structural VAR	It has been determined that positive shock on renewable energy consumption increases GDP and reduces CO ₂ emissions, and positive shock on GDP has a very high positive effect on CO ₂ emissions. Variance decomposition explains a significant portion of the GDP estimate error variance of the share of renewable energy consumption and a relatively smaller or negligible portion of the estimate error variance of CO ₂ emissions
Tugcu et al., (2012)	G7 countries	1980-2009	Autoregressive Distributed Lag approach, Hatemi-J (2012) causality test	Long-term forecasts have shown that renewable or non-renewable energy consumption is more effective in explaining the considered relationship for economic growth and increased production function. On the other hand, in the case of the classic production function, bidirectional causality was found for all countries, but when the production function is increased, mixed results are found for each country
Ocal and Aslan (2013)	Turkey	1990-2010	Panel unit root tests, ARDL cointegration analysis and Toda-Yamamoto causality analysis	It has been determined that the increase in renewable energy consumption has a negative effect on economic growth. On the other hand, the existence of one-way causality has been determined from economic growth to renewable energy consumption
Pao and Fu (2013)	Brazil	1980-2010	Time series unit root tests, Peer integration analysis, ECM and causality analysis	While there was a one-way causality relationship from non-hydroelectric renewable energy consumption to economic growth, a mutual causality was found between total energy consumption and economic growth
Sebri and Ben-Salha (2014)	BRICS	1971-2010	ARDL Bound Test, VECM	As a result, a mutual causality relationship was found between economic growth and renewable energy use
Bloch et al. (2015)	China	1977-2013	Structural Fracture Test, ARDL Cointegration, VECM Granger Causality	In the long term, a bidirectional causality relationship has been determined between renewable energy consumption and economic growth
Destek (2016)	Newly industrialized countries	1971-2011	Asymmetric Causality Approach	As a result, GDP decreases as renewable energy use increases for South Africa and Mexico. There is a directly proportional relationship for India. No relationship has been found for Brazil and Mexico
Inglesi-Lotz (2016)	OECD countries	1990-2010	Panel cointegration test	Renewable energy consumption or its share in total energy mix has a positive and statistically significant effect on economic growth. From a policy perspective, supporting renewable energies benefits not only the environment, but also the economic conditions of countries
Bhattacharya et al., (2016)	38 countries	1991-2012	Panel Cointegration, DOLS, Panel FMOLS, Panel Causality	For the long term in 57% of the selected countries; It was concluded that the increase in renewable energy consumption had a significant and positive effect on economic output
Amri (2017)	72 developing countries	1990-2012	GMM	As a result of the study conducted by using the dynamic simultaneous equation model by grouping the countries according to their income levels and development levels, they found a mutual relationship between renewable energy use and income level, trade and renewable energy use, trade and income level
Ito (2017)	42 developing countries	2002-2011	GMM	As a result, non-renewable energy sources have a negative effect on economic growth and renewable energy sources have a positive effect
Syzdykova et al., (2020)	CIS	1992-2018	Panel Cointegration, Panel Causality	A bidirectional relationship has been found for the CIS countries, so that the feedback hypothesis is valid in these countries
Rahman and Velayutham (2020)	South Asian countries	1990-2014	panel FMOLS and panel DOLS, Dumitrescu-Hurlin (2012) panel causality	They found that the conservation hypothesis is valid for South Asian countries

Source: Created by the authors

Table 4: Variables used in the model

Variable code	Variable name	Description	Expected effect
gdp (dependent variable)	Economic growth	GDP per capita	
rec	Renewable energy consumption	Renewable energy use share in total energy use	+
fec	Fossil based energy consumption	Fossil-based energy use share in total energy use	+
coe	CO ₂ Emission	CO ₂ emission per capita	+

While analyzing the relationship between renewable energy use and economic growth in the literature, non-renewable energy sources are also added to the model in general. Also, CO₂ emissions are included in the model and are accepted as an explanatory variable on growth. Accordingly, the model (1) installed can be shown as follows:

$$gdp_{it} = \alpha_{it} + \beta1_{it}gdp_{i,t-1} + \beta2_{it}rec_{it} + \beta3_{it}fec_{it} + \beta4_{it}coe_{it} + \epsilon_{it}$$

In the model, *gdp* is the dependent variable. The effects of the independent variables *rec*, *fec*, and *coe* are tested as a variable used in measuring economic growth. As a result of the studies in the literature, *rec* and *fec* variables are thought to be effective on economic growth since energy is an important production input. Therefore, *rec* and *fec* variables are expected to have a positive effect on *gdp*, *coe*. Is considered as a reflection of all emitting energy sources. This variable is theoretically added to the model based on the Environmental Kuznets Curve. This curve showing economic growth and environmental pollution are inverted U-shaped. This curve argues that as the economic growth rate of a country increases, environmental pollution will increase, but it will reverse after a certain income level. This variable is expected to have a positive impact on economic growth, as developing countries are countries that cannot enter as long as environmental damage is reduced and are indicative of other energy sources emitting *coe*.

4.2. Econometric Methodology

In this study, a 2-step procedure was applied to investigate the relationship between renewable-non-renewable energy sources and economic growth. In step one, the stasis levels of the series were tested with unit root tests developed by Im et al. (2003) and Maddala and Wu (1999). In the second step, the econometric relationship between variables dynamic panel data methodology was explored with system GMM estimators proposed by Arellano and Bond (1991) and Arellano-Bover (1995).

4.2.1. Panel unit root tests

Since the panel data has the size of the time series, it is important to perform stationary testing in order to reflect the realistic relationship of the results. Misleading results are obtained when experimental analysis is made between non-stationary series (Syzdykova et al., 2019). Im et al., (2003) and Maddala and Wu (1999) tests were used in the study. Im et al., (2003) consider a regression equation as follows:

$$\Delta Y_{it} = \mu_i + \beta_i Y$$

Where $I = 1, 2, \dots, N$ and $t = 1, 2, \dots, T$ will be. In this test, the zero hypothesis is established as “ $\beta_i = 0$ for all i (i.e. horizontal cross-sectional units),” while the alternative hypothesis is formed as “ $\beta_i < 0$ for at least one i .” The critical values required for this test are taken from table values in Im et al., (2003). Here, the T statistic for each horizontal cross-section unit is calculated as $t_i = \beta_i / sh(\beta_i)$. Then, the \bar{z} statistic is obtained as follows:

$$\bar{z} = \left(\frac{\sqrt{N}(\bar{t} - E(\bar{t}))}{\text{Var}(\bar{t})} \right) \quad N(0,1)$$

$$\bar{t} = \frac{1}{N} \left(\sum_{i=1}^N t_i \right)$$

The panel unit root test developed by Maddala and Wu (1999), also known as the Fisher ADF test, proposed a Fisher type test based on the combination of p values obtained from unit root test statistics for each horizontal section:

$$P = -2 \sum_{i=1}^N \ln p_i$$

P exhibits a χ^2 distribution with a $2N$ degree of freedom. The Fisher ADF test does not require a balanced panel data, but can use different lengths of lag in individual ADF regressions.

4.2.2. Dynamic panel data analysis and gmm estimators

Many economic relationships that are the subject of the research may be static or determined by a dynamic process. While panel data analysis can be applied to static processes, it can be applied within the analysis of dynamic processes. There are dynamic panel data models developed for this purpose. A dynamic panel data model, including the lagged value of the dependent variable, can be written as follows:

$$y_{it} = x'_{it}\beta + y_{i,t-1} + c_i + \mu_{it}$$

However, such an equation formulation has an important problem. The lagged value of the dependent variable included in the model is associated with the combined error term $\delta_{it} = c_i + \epsilon_{i,t}$. The main reason for this is that c_i , which expresses the heterogeneity specific to the sections, is the same for each observation of each group. The method currently used and popular in the literature is the Generalized Moments Method (GMM) (Arellano and Bond [1991] and Arellano and Bover [1995]) estimators (Greene, 2012: 497).

Arellano-Bond and Arellano-Bover estimators;

- Short periods and panels with a large number of sections (small T and large N)
- Presence of linear functional relationship
- In dynamic processes, that is, when the current value of the dependent variable depends on the past values
- Cases where independent variables are not strict external
- Existence of cross-sectional heterogeneity
- It can be used in the presence of section-specific autocorrelation and varying variance only when it does not exist between sections (Roodman, 2009: 86).

The GMM estimator for dynamic panel data has been widely used recently, especially in economic growth regressions. GMM is generally a semi-parametric efficient estimation method. There are significant advantages to using the GMM panel estimator over horizontal section estimators. First; it is possible to control time constant effects and country (horizontal-cross-section) constant effects. Second, the appropriate delays of the arguments can be used as tool variables that take into account the possible internality of the arguments. The GMM panel estimator provides

Table 5: Panel unit root test results

Variables	Level		1 st difference	
	IPS	Fisher ADF	IPS	Fisher ADF
gdp	11.638(0.801)	80.489(0.734)	-2.920(0.001)*	102.608(0.000)*
rec	-4.817(0.000)*	120.708(0.000)*	-	-
fec	-1.308(0.002)*	80.865(0.002)*	-	-
coe	9.579(0.204)	76.097(0.199)	-2.821(0.002)*	73.098(0.009)*

The numbers in parentheses for the IPS test are the p values for the average t statistics. The numbers in parentheses for the Fisher ADF test are the p values for the Fisher ADF χ^2 statistics.
 *It shows that the statistic is significant at the level of 1% significance

the opportunity to solve such econometric problems by using lagged values of independent variables (Arellano and Bond, 1991; Arellano and Bover, 1995).

Within the framework of the above model (1), a dynamic panel regression equation proposed by Arellano and Bond (1991) can be considered:

$$gdp_{it} = \alpha gdp_{i,t-1} + \beta' X_{it} + \eta_i + \varepsilon_{it}$$

Where gdp_{it} is the per capita income of the I country at T time, $gdp_{i,t-1}$ is the per capita income of the I country at T-1 time; $X_{i,t}$ denotes the set of variables containing arguments, and ε_{it} equal denotes the error term. Another feature of the dynamic regression equation is that the delayed state of the dependent variable is included in the equation. α and β mean the parameter of the delayed value of the dependent variable and the vector of parameters consisting of the parameters of the independent variables, respectively.

5. RESULTS

Two different unit root tests (IPS and Fisher ADF) were used to test the stasis level of variables. Panel unit root test results are seen in Table 5. The unit root Statistics reported here express the level values of the variables. The zero hypothesis, which refers to the existence of a unit root for each variable, could not be rejected for different levels of significance for the gdp and coe variables. If the model contains a trend from deterministic components, it is also seen that the level values are not stable. This means that the shock effects on the series do not disappear over time. When the first difference of the variables is taken, the statistic becomes stationary according to the test values, that is, it carries the I (1) process. rec and fec variables were found to be stationary in their level values I (0).

According to the Wald test result in Table 6, it is seen that the explanatory variables are significant in explaining the dependent variable together. Sargan test, on the other hand, shows that vehicle variables do not have internality problems as desired, therefore vehicle variables are valid. Also, the presence of 1st degree and 2nd-degree autocorrelation was tested in the model and AR (1) test statistics were negative and significant as desired; AR (2) test statistics were obtained as meaningless. Thus, according to the findings, it was concluded that while the presence of 1st-degree autocorrelation was not available, 2nd-degree autocorrelation was not in question.

Table 6: GMM application results

Variables and tests	Coefficients (probability values)
$gdp_{i,t-1}$	0.965514 (0.0000)*
rec_{it}	0.007644 (0.0000)*
fec_{it}	0.035021 (0.0000)*
coe_{it}	0.001612 (0.0000)*
Wald test (χ^2)	$\chi^2 (6) = 1972.71 [0.0001]*$
Sargan test	$\chi^2 (53) = 26.20239 [0.9783]$
AR(1) Arellano bond autocorrelation test	-3.8254 [0.0001]*
AR(2) Arellano bond autocorrelation test	-1.1835 [0.2078]

*%1 and ** %5 represent significance

According to the estimation results obtained from the model, the lagged value of the dependent variable, renewable energy consumption, fossil energy consumption, and CO₂ emission have a positive effect on economic growth. 1% increase in the share of renewable energy use increases GDP per capita by 0.07688%. The 1% increase in the share of use of fossil-based energy resources increases GDP per capita by 0.35021%.

Fossil energy consumption for developing countries has more impact on economic growth than renewable energy consumption. However, this should not mean increasing the trend towards fossil-based fuels. This result is due to the lower share of renewable energy systems in the global energy market compared to fossil-based energy systems. This situation will reverse as the share of renewable energy use in total energy consumption increases over time. It is an expected result that CO₂ emissions are directly proportional to ecological growth. Developing countries are generally countries that have not yet reached the desired level in terms of income. CO₂ emissions are also expected to decrease when the level of income is reached and the share of renewable energy use in final energy use is increased.

6. CONCLUSION

Energy supply should be supported with renewable energy systems to meet the increasing energy demand throughout the world and to regulate the fluctuating energy prices so as not to harm the national economies. In this context, it is thought that renewable energy will play a more important role in the future in achieving economic growth targets. Although the relationship between economic growth and renewable energy consumption has been investigated in many studies, it is not a consensus issue. In addition to working with different countries and data sets, the difference between the model and the econometric tests that were handled was also influential.

In this study, the effects of renewable energy use, fossil energy use, and CO₂ emissions on economic growth were examined for selected developing countries (Brazil, India, Indonesia, China, Chile, Mexico, South Africa and Turkey). In the study, GMM estimator, one of the dynamic panel data methods, was used for empirical analysis of the relationship between these variables. Based on the findings, the 1% increase in the share of renewable energy use increases the per capita GDP by 0.07688% in developing countries included in the analysis, while the 1% increase in the share of fossil-based energy resources increases the per capita GDP by 0.35021%. One of the factors that will direct-developing countries to renewable energy; is the fact that fossil energy threatens environmental health, although it causes growth. The analysis is that renewable energy investments for developing countries are the right political decision in terms of both economic and environmental aspects. The main goal for developing countries is to create a more sustainable energy resource pool where renewable energy sources play an important role.

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