

The Role of Renewable Energy and R&D Expenditures in the Economies of BRICS Countries

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Abstract: Countries will ensure energy supply security to increase their supply sources and reduce their dependence on imported fossil energy sources, they turn to various avenues to benefit from new and renewable energy sources. In this study, the effects of renewable energy production on economic growth are examined from the perspective of the renewable energy policies of BRICS (Brazil, Russia, India, China, South Africa) countries in the context of the renewable energy sector. In addition, per capita research and development (R&D) expenditures are also included in the analysis to measure the relationship between renewable energy sources and R&D expenditures. In this context, the analysis was carried out with the data of the BRICS countries between 1996 and 2015. The result of the panel analysis and the Driscoll-Kraay estimator gives a meaningful result. However, no significant relationship was found between the amount of energy produced from renewable sources and economic growth. As a result of the correlation relationship, it is seen that the relationship between economic growth and R&D data in BRICS countries is at a very strong level. The findings of this study strongly support endogenous and Schumpeterian growth approaches. The statistically insignificant impact of renewable energy production on economic growth in BRICS countries is consistent with neoclassical and energy-based growth models. In contrast, the strong relationship between per capita R&D expenditure and economic growth confirms the validity of knowledge and innovation-driven growth theories.

Keywords: electricity production, research and development (R&D) expenditures, renewable energy, renewable electricity

1 Introduction

Since the beginning of time, the importance of energy to human existence has only grown. The primary explanation for this phenomenon is that energy is required in all aspects of daily living, including but not limited to transportation, climate control, and heating and cooling the home. In addition, the availability of energy is critical to the growth of a nation [1]. Since current trends in energy consumption are expected to double from their present levels by the year 2050, it is impossible to deny that energy is the single most essential factor contributing to the advancement of economic growth, as stated by the World Energy Council (2007) [2]. Because of this, problems about the usage of non-renewable energy sources, climate change, and economic development are of the utmost significance. According to the European Commission (EC), 2011, it is projected that the percentage of renewable energy sources (RES) in Europe will increase significantly in all future scenarios, eventually reaching at least 55% of gross final energy consumption in 2050. This represents a 45% increase from the current level of approximately 10% [3].

The objective for nations is to provide their inhabitants with the energy they need to utilize at the lowest cost that is practically possible [4][5]. Because of this, the great majority of countries have energy policies in place to assure that they will [6].

Electricity now accounts for around 19% of total energy consumption; however, this percentage is anticipated to considerably expand as a greater number of nations electrify their economies (IEA, 2018) [7]. Since the production of energy is one of the primary contributors to climate change, several nations have developed strategies and regulations to significantly increase their percentage of renewable power in the years to come [3][8]. They are investigating how much it is possible to reduce electricity demand, especially over long periods of time, without incurring huge economic costs [9].

Demand for renewable energy is outstripping supply, raising tensions with little government ability to reduce these tensions. In Latin America, tension stems from a dilemma in this scenario with hydropower, which is desirable but foresees difficulties for expansion due to environmental concerns (land use, biodiversity loss and resettlement). In Latin America, government actions support the shares of oil, gas, biomass, and hydro in the first two periods (2020 and 2035) and only later, with increasing oil and gas shortages (after 2035), the mix is predicted to change [2].

Several theoretical and empirical research [10-12], among others, have shown that collaboration with external partners is a primary factor in the development of environmentally friendly innovations [13-15]. It has been shown that investments in R&D play a significant part in the achievement of long-term, sustainable economic growth in many nations across the globe. In addition, businesses are becoming aware that investments in R&D are becoming more crucial because they may provide advantages that have the potential to result in sustainable corporate

development in the future [16]. However, R&D may be carried out for the benefit of other firms or purchased from other firms under contractual agreements. In addition, not all costs incurred during R&D activities are considered R&D expenditures.

R&D refers to any creative endeavors that are methodically applied to the expansion of knowledge to generate new applications [17]. Investments in R&D are one of the primary factors that determine a nation's level of development and competitiveness [18]. R&D expenditures are among the important parameters of a country's economic development. The increase in R&D expenditures contributes to the development of export capacities, on the other hand, by enabling countries to transform their production processes and increase their quality production levels [19].

For nations to succeed in their mission to become more competitive on the international stage, it is imperative that they promote and sustain high levels of expenditure on R&D operations. The economic and science and technology policy community has adopted the R&D intensity ratio as an indicator of the degree to which support is provided for R&D. This ratio calculates the gross domestic expenditure on research and development (GERD) as a percentage of the gross domestic product (GDP) [20].

Economic growth means a significant increase in national income in each calculation period. The promotion of economic expansion ranks high on the list of priorities at the forefront of practically every nation's aspiration for the future. Because of this, the rate of economic development is influenced by a wide variety of variables, both good and negative [21][22]. One of the most important conditions for economic growth and gaining competitive power in the international arena is the innovations made in the technological field. Technological innovations emerge because of R&D.

The basis of R&D is all the activities for R&D and the expenditures made for these activities [23]. In the literature, there are many studies investigating the relationship between R&D expenditures and economic growth [23-30]. In general, empirical studies have concluded that R&D expenditures have a positive and significant effect on economic growth.

The expansion of the components is intimately tied to ensuring economic growth. When we examine the experiences of industrialized nations, it becomes clear that they place a high value on technologically advanced manufacturing and export. The causation link between R&D, activities leading to innovation, export, and growth in this regard becomes a crucial problem [28].

Because governments recognize the significance of private R&D expenditures, they use a variety of public assistance instruments to persuade businesses to spend extra private dollars in R&D endeavors. Although the role of the government sector as a performer of R&D is relatively limited, the government sector is a key sponsor of

R&D carried out in the business sector [31]. As a result of rapid population growth, urbanization, industrialization, wide-spread use of technology and welfare increase in the world economy, energy demand increases rapidly, and the importance of energy supply security emerges. However, the innovation of a country's economy is one of the key factors driving economic growth and competitiveness today.

Brazil, Russia, India, China, and South Africa, among the developing countries, are grouped as BRICS countries due to their rapidly developing economies and similar economic structures [32]. BRICS nations have all enjoyed fast economic development, have big foreign currency reserves, and attract a considerable amount of foreign direct investment [33]. The BRICS countries represent approximately 42.20% of the world's total population and 30% of the total land area. However, BRICS is not a regional union; It is a bloc of emerging economies created to strengthen their 'strategic position' in an almost unipolar world scenario. The nations that make up the BRICS group are the leading political forces in the contemporary world. According to Pao and Tsai [34] the BRICS nations will have a greater GDP than the G7 countries by the year 2050.

According to the statistics that were published by the World Bank, during the period of 2000-2018, the electricity production in the countries that make up the Group of Seven (G7), which are the seven largest economies in the world, was 0.4%, the European Union's production was approximately 0.8%, and the Organization for Economic Cooperation and Development (OECD) countries' production was approximately 0.8%. Although it was stated that there was an increase of 0.4% in the countries and approximately 3% in the worldwide electricity production, it was stated that the electricity production in the BRICS economies increased by 6.7% in the relevant period. The authors of the article [6] investigated the effect that the production of electricity had on the rate of industrialization and the rate of sustainable economic growth in the BRICS nations from the years 2000 to 2018. According to the findings of the research, the generation of energy in the BRICS nations has a beneficial impact, not only on the production of industrial goods but also on the expansion of the economy in a sustainable manner.

According to Simonova et al. [35] there is an increase in the share of oil in the primary energy consumption structure according to BRICS, but while the indicator of China tends to decrease (2006-20.6%, 2017-19.4%), oil its share fell significantly in all countries except India, where this indicator almost kept its previous value (2006-56.1%, 2017-56.2%). According to Barykina et al. [36] the nations that make up the BRICS group will remain significant participants in the energy market. According to the BRICS countries, by the year 2040, hydrocarbon fuels will continue to dominate the energy balance of the BRICS countries, meeting approximately three-quarters of the total demand. In addition, nuclear energy will be developed, and projects to implement renewable energy will be carried out. Investment in renewable energy is increasing significantly in the BRICS economies. In 2015, the top six countries such as Brazil, Russia, India, China, USA and Canada accounted for 63% of the total world hydroelectric installed capacity. It can be said

that these six countries constitute 45% of the total hydroelectricity production in the world [37].

This study seeks to answer the question of whether renewable energy and R&D expenditures have an impact on economic growth in BRICS countries. The positive effects of renewable energy on human development have been confirmed for the BRICS countries [38]. Today, economic growth is measured by the strategic policies taken by the state and the investments it makes per capita. R&D is one such investment. Considering all these, the aim of this study is to measure the place of renewable energy production and per capita R&D expenditures in the measurement of economic growth in BRICS countries. Because realizing economic growth, which is among the most basic goals in front of countries, is possible by gaining superiority in different and key areas.

2 Theoretical Background

The economic growth literature has developed different theoretical approaches to explain the long-term welfare increase of countries. Different characteristics have been the focus of these models and approaches. A review of the literature on the effects of energy use, renewable energy sources, and R&D expenditures on economic growth reveals that this topic has been examined within the framework of both neoclassical and modern growth theories. Accordingly, considering the aim of this study, the effects of renewable energy production and per capita R&D expenditures on economic growth in BRICS countries have been examined, taking into account the relevant economic growth models.

According to neoclassical growth theory, the source of long-term economic growth is technological development, and technology is considered an exogenous variable [39][40]. While the energy factor is not explicitly included in the classical Solow model, it has been included as a complementary input to the production function in later studies. Endogenous growth theories, by including the source of economic growth within the model, treat technological progress and knowledge accumulation as endogenous variables [41][42] (Romer, 1986; Lucas, 1988). According to this approach, R&D activities, human capital, and innovation are key determinants of economic growth. Romer [43] argued that R&D investments increase total factor productivity by developing new products and production techniques, and that this process supports long-term economic growth. Similarly, Lucas [42] drew attention to the lasting impact of human capital accumulation and learning processes on growth. There are studies in the literature showing that R&D intensity is particularly decisive on growth performance in developing countries [44][45].

Models aimed at explaining the energy-growth relationship consider energy as one of the basic inputs of the production function. In this approach, the production function is generally expanded to include capital, labor, and energy components [46]. While renewable energy provides an environmental sustainability advantage

compared to fossil fuels, its impact on economic growth is closely related to the technological infrastructure, investment costs, and energy transition process of countries [47]. While some studies have found a positive relationship between renewable energy and economic growth [48], others have stated that this relationship is weak or insignificant.

According to the Schumpeterian growth theory [49] (Schumpeter, 1934), which explains economic growth through innovation, entrepreneurship and the process of “creative destruction”, R&D activities are the primary source of technological innovations and productivity increases. Aghion and Howitt [50] argued that R&D investments support growth in the long term and ensure the continuity of technological progress. It should be noted that the theoretical basis of this study is mainly based on endogenous growth and Schumpeterian growth theories.

In line with the aim of the study, the following hypotheses were formulated and tested:

- H₁:** Renewable energy production has a positive and significant impact on economic growth in BRICS countries.
- H₂:** Per capita R&D expenditures have a positive and significant impact on economic growth in BRICS countries.

2.1 Renewable Electricity Production

The literature on the use of renewable energy sources in electricity generation is generally shaped around the axes of sustainable development, energy supply security, and environmental impacts. Renewable sources such as wind, solar, and geothermal are considered as alternatives to fossil fuels and are highlighted, particularly due to their potential to reduce environmental externalities [51, 52, 53, 54]. However, the literature shows that the findings regarding the economic impacts of renewable energy are not homogeneous.

One group of studies argues that renewable energy investments strengthen electricity supply security in the long term and support sustainable development. The European Commission's scenario analyses reveal that the share of electricity in total final energy demand will increase and that energy systems need to be significantly decarbonized [3]. Similarly, Pereira Jr. et al. [55] and Fleten and Ringen [56] emphasize that increasing renewable energy capacity is important for system integrity, especially in the case of Brazil. However, since a significant portion of these studies are based on scenario analyses and model assumptions, empirical evidence regarding actual economic outcomes is limited. In contrast, some studies adopt a more cautious approach to the cost structure and economic feasibility of renewable energy-based electricity systems. In particular, high capital costs, balancing capacity, storage, and the need for infrastructure investments indicate that renewable energy-intensive systems may increase electricity prices in

the short and medium term [3][57]. Walmsley et al. [58] argue that the sustainability of renewable energy technologies should be comprehensively evaluated through indicators such as energy return rate (EROI) and resource use factor, and take a critical approach to the “100% renewable system” discourse. This finding clearly reveals the tension between normative goals frequently mentioned in the literature and technical and economic realities. Studies examining policy instruments show that the economic impacts of renewable energy depend on the support mechanisms implemented. Examining auction-based support systems [59] reveals that these mechanisms are more effective and cost-efficient compared to previous incentive systems. This situation shows that the economic effects of renewable energy are closely related not only to technological but also to institutional and governance factors.

Studies conducted specifically on BRICS countries, however, present more heterogeneous results. While Yu et al. [6] and Ummalla et al. [60] show that electricity production and especially hydroelectric consumption have positive effects on economic growth; Yıldırım et al. [61] and Khan and Osińska [62] show that the energy consumption–growth relationship differs according to countries and energy types. This confirms the issue of country-specific effects and energy type distinction, which is widely discussed in the energy-growth literature. However, a significant portion of studies focusing on BRICS countries focus on total energy consumption or specific energy types (e.g., hydroelectric); the number of studies that address the direct impact of renewable energy on economic growth together with R&D, technology and structural transformation variables remains limited [35, 36, 63]. De Oliveira and Moutinho [64], on the other hand, consider the relationship between energy consumption and economic growth together with globalization indicators, emphasizing the impact of social and political factors on growth; this shows that the energy-growth relationship should be evaluated within a multidimensional framework. In general, the literature shows that renewable energy sources are indispensable in terms of environmental sustainability, but their effects on economic growth are time-lagged, indirect, and politically context-sensitive. This situation indicates that the contribution of renewable energy to economic growth should be evaluated not only through the amount of production but also together with the level of technology, R&D investments, and institutional structure. Although this study did not find a significant relationship between renewable energy production and economic growth, it showed a strong effect of R&D expenditures, thus providing a contribution consistent with these critical findings in the literature.

2.2 Research and Development Expenditures

R&D activities are considered one of the key determinants of economic growth through knowledge production and innovation capacity. According to Abdullah and Afshar [65], R&D is a systematic and creative process that encompasses not only

technical knowledge accumulation but also social and cultural knowledge. This broad definition shows that the effects of R&D expenditures on economic growth are not limited to increased production; they should also be evaluated through elements such as institutional capacity, absorption capacity, and long-term competitiveness [10, 66, 67].

However, the relationship between R&D expenditures and economic growth does not yield a one-way and consistent result in the literature. For example, Sylwester [68] could not find a significant relationship between R&D expenditures and economic growth for OECD countries, while he showed that industrial R&D expenditures positively affected growth in G7 countries. This finding reveals that the effect of R&D on growth can vary depending on country groups and the nature of R&D (public/private, industrial/academic).

Studies focusing on developing and emerging economies, however, present more heterogeneous results. Cai [69] compared BRICS and G7 countries within the framework of the national innovation systems (NIS) approach; he found that China and India have relatively high innovation performance, while South Africa lags behind due to weak R&D infrastructure and institutional deficiencies. These results show that institutional structure and technology infrastructure are critical for R&D expenditures to support growth.

A significant portion of panel data studies focusing on BRICS and BRICS-T countries reveal that R&D expenditures have positive and statistically significant effects on economic growth [29, 70, 71]. However, most of these studies analyze the short-term effects of R&D expenditures and address the lag effect issue in a limited way. Özek [72], on the other hand, points out that the effect of R&D expenditures on growth only appears in the long term, drawing attention to this lagged effect, which is often overlooked in the literature.

Studies arguing that R&D affects economic growth indirectly are also noteworthy. Çetin [73] shows that R&D expenditures increase high-technology exports; and high-technology exports support growth. Similarly, Boz et al. [19] and Durmaz and Yıldız [74] reveal that variables such as patents, technology transfer, and high-quality product exports are intermediary mechanisms between R&D and growth. These findings show that the R&D-growth relationship operates indirectly, not directly, through innovation and foreign trade channels. Studies in developed economies show that the impact of R&D on growth is more pronounced. Oğuz [23] and Sarıdoğan [30] found that R&D expenditures significantly increased economic growth in G8 and European Union countries. Similarly, studies using innovation indicators such as patents and trademarks show that the impact of innovation on growth is stronger in G7 countries [75]. This suggests that mature innovation ecosystems are needed for R&D investments to translate into growth. In general, the literature shows that the impact of R&D expenditures on economic growth varies depending on the level of development of countries, their institutional capacity, technological infrastructure, and the sectors to which R&D is directed. In

this context, the assumption that R&D expenditures automatically lead to growth under all circumstances should be critically questioned. A significant contribution of studies on BRICS countries is that they show that the growth-promoting effect of R&D mostly emerges in the long term and through indirect channels.

3 Methods

3.1 Purpose of the Study

The aim of this study is to analyze the effects of renewable energy use on economic growth and the relationship of renewable energy resources with R&D expenditures in the perspective of renewable energy policies of BRICS countries, which are the leading countries in the renewable energy sector, based on the data between 1996 and 2015. Since the data obtained from the World Bank is limited to 2015.

3.2 Data Set and Analysis Method

To the research, data on renewable electrical energy production, per capita R&D expenditures, and economic growth were compiled and analyzed using the panel analysis. This was done so that the researchers could determine how the presence of electrical energy derived from renewable sources affects economic growth and how this affects the relationship between R&D expenditures and economic growth. Information on the wage policy that was allotted to R&D expenditures per capita during the years in the countries that were used as an example before the study was carried out.

The data set used in the study includes the annual data of four countries from the five BRICS member countries. The said countries are Brazil, Russia, China, and South Africa, respectively. Since the data of India, which is one of the member countries, is very scattered and incompletely explained, it is out of the scope of the analysis. The data set was obtained from the World Bank. Since R&D expenditures were announced after 1996 and renewable energy production until 2015, the data set was limited in this period.

4 Analysis and Results

The data set used during the analysis was made in accordance with the balanced panel analysis. In the model, economic growth was used as the dependent variable,

and renewable energy production and R&D expenditures were used as the independent variables. The logarithms of the variables were taken and included in the analysis. The special statistical data of the variables applied on their logarithmic values are given in Table 1.

Table 1
Special statistics of variables after logarithmic transformation

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
Renewable energy output	80	30.92267	33.01481	0.4177333	93.56113
R&D expenditures	80	2.905658	0.4000235	2.29776	3.579468

Source: Obtained as a result of the Stata program used in the study.

After examining the statistics of the data set, the necessary model for the analysis was established (Equation 1).

$$LGDP = \beta_0 + \beta_1(\text{Renewable Energy Output}) + \beta_2(\text{R\&D Expenditure}) + \varepsilon \quad (1)$$

In panel data models, the Likelihood Ratio (LR) test is used to determine the validity of the classical model, that is, whether individual and/or time effects are present. The LR test compares the classical model (restricted model) with the random effects model (unrestricted model). Both the classical model and the random effects model are estimated using the maximum likelihood method, and the log-likelihood values obtained from these estimations are used to compute the LR test statistic. The LR test statistic is calculated as follows:

$$LR = -2[\ln L_R - \ln L_U] \quad (2)$$

where $\ln L_R$ denotes the log-likelihood value of the classical model and $\ln L_U$ denotes the log-likelihood value of the random effects model. The LR test statistic follows a chi-square distribution with q degrees of freedom, where q represents the number of restrictions. Rejection of the null hypothesis indicates that the classical model is not appropriate and that individual effects, time effects, or both are present in the panel data model.

Hypotheses:

H₀: Classical model suitable

H₁: Classical model not suitable

If the H₀ hypothesis is rejected, it is decided that there are unit, time or both unit and time effects, that is, the classical model is not suitable.

Within the framework of this information, the Likelihood ratio (LR) test results are given in Table 2.

Table 2
Likelihood ratio (LR) test results

Criteria	LR Statistics	Probability Value
Unit and Time Impact	127.96	0.0000
Unit Impact	75.69	0.0000
Time Effect	0.93	0.1680

Source: Prepared by the author as a result of the analysis.

Hypotheses:

- For unit and/or time effect:

$$\mathbf{H_0:} \quad \sigma_{\mu}^2 = \sigma_{\lambda}^2 = 0$$

$$\mathbf{H_1:} \quad \sigma_{\mu}^2 \neq 0 \text{ and/or } \sigma_{\lambda}^2 \neq 0$$

- For unit effect only:

$$\mathbf{H_0:} \quad \sigma_{\mu}^2 = 0$$

$$\mathbf{H_1:} \quad \sigma_{\mu}^2 \neq 0$$

- For time effects only:

$$\mathbf{H_0:} \quad \sigma_{\lambda}^2 = 0$$

$$\mathbf{H_1:} \quad \sigma_{\lambda}^2 \neq 0$$

The hypotheses concerning the presence of unit and time effects are specified in terms of the variance components of the error structure. The joint null hypothesis that neither unit-specific nor time-specific effects are present is tested against the alternative that at least one of these effects exists. According to the results reported in the table, the null hypothesis is rejected, indicating the presence of at least one type of effect in the model. Subsequent tests reveal that the variance component associated with unit effects is statistically significant, implying the existence of unit-specific heterogeneity. Therefore, the classical model, which assumes no individual effects, is deemed inappropriate. In contrast, the null hypothesis that the variance component of time effects is equal to zero cannot be rejected. This result suggests that time-specific effects are not present in the model. Consequently, the appropriate specification is a panel data model with unit effects only.

According to the results of the Likelihood Ratio (LR) test, only the existence of unit effect was determined in the model, and it was understood that there was no time effect. In the next step, it is necessary to determine whether this unit effect is constant or random, that is, whether it is correlated with independent variables.

Then Hausman and Rhausman tests were started. The Hausman test tests whether the explanatory variables and the unit (time) effects are correlated.

Hypotheses:

H₀: The random effects model is suitable

H₁: Fixed effects model is suitable

When computing the Hausman test statistic, Hausman and Taylor [76] use the difference in the variance covariance matrices of the generalized EKK estimator and the within-group estimate to get the H statistic. The Hausman test then evaluates whether this difference is equal to zero. The random effects model is valid if the difference between the parameters is not systematic; however, if the difference between the parameters is systematic, the fixed effects model is valid.

The results of the Hausman Test, which is used to choose between fixed effects and random effects models, and the robust Hausman Test, which can be used if there is a deviation from an assumption that impairs the efficiency, are as follows: the Hausman Test is used to choose between fixed effects and random effects models; the robust Hausman Test is used if there is a deviation from an assumption that impairs the efficiency (Table 3).

Table 3
Hausman and Rhausman test results

Test Name	Test Statistics	Probability Value
Hausman	1.58	0.4541
Rhausman	0.02	0.9908

Source: Prepared by the author as a result of the analysis.

Hypotheses:

H₀: $E(\varepsilon_{it}|X_{it}) = 0$. (The random effects model is appropriate)

H₁: $E(\varepsilon_{it}|X_{it}) \neq 0$. (Fixed effects model appropriate)

According to the table, H₀ hypothesis cannot be rejected.

In this context, the random effects estimator is deemed appropriate. The results of the Hausman and robust Hausman tests indicate that the model is best specified as a one-way random effects model incorporating only unit-specific effects. Accordingly, the model is estimated using the Generalized Estimated Quadratic Components (EQC) method, which is consistent with the random effects framework. Following the estimation, the fundamental model assumptions are subsequently examined.

Whether the random effects model complies with the assumption of equal variance within the unit and according to the units was tested by Levene, Brown and Forsythe's Tests [77].

Table 4
Test results of Levene, Brown and Forsythe

Test Name	Test Statistic
W0	27.168113
W50	19.175574
W10	26.377375

Source: Prepared by the author as a result of the analysis.

Hypotheses:

H₀: There is no heteroskedasticity

H₁: There is heteroskedasticity

The H₀ hypothesis, which is established by comparing the test statistics of Levene, Brown and Forsythe (W0, W50, W10) with the Snedecor F table with degrees of freedom, is rejected. There is heteroskedasticity in the model.

Whether the model is autocorrelation or not was tested with Bhargava [78] Franzini and Narendranathan's Durbin-Watson and Baltagi-Wu's by Baltagi Local Best Invariant Tests [79].

The hypotheses of the Durbin-Watson test in which the H₀ hypothesis that the autocorrelation coefficient ρ is equal to zero is tested:

H₀: $\rho = 0$ (There is no autocorrelation)

H₁: $|\rho| \neq 1$ (There is autocorrelation)

The hypotheses for Baltagi-Wu's Local Best Invariant Test are:

H₀: $\rho = 0$ (There is no autocorrelation)

H_a⁺: $\rho > 0$ (There is positive autocorrelation)

H_a⁻: $\rho < 0$ (There is negative autocorrelation)

Table 5
LBI Test Results by Durbin Watson and Baltagi-Wu

Test Name	Value
Durbin Watson	0.14258086
Baltagi-Wu'nun LBI	0.2479822

Source: Prepared by the author as a result of the analysis.

Hypotheses:

H₀: There is no autocorrelation

H₁: There is autocorrelation

Since the statistical values of both tests are less than 2, there is autocorrelation for the random effects model.

Whether the model is spatially uncorrelated, that is, uncorrelated between units, was tested with the tests of Pesaran and Friedman [80].

Table 6
Test results of Pesaran, Friedman, and Frees

Test Name	Test Statistics	Probability Value
Pesaran CD	4.882	0.0000
Friedman	46.958	0.0000

Source: Prepared by the author as a result of the analysis.

Hypotheses:

H₀: No correlation between units

H₁: There is correlation between units

As the probability values are less than 0.05 because of both tests, the H₀ hypotheses are rejected, and it is understood that there is a correlation between the units.

Multicollinearity (MC), which arises from strong correlations among independent variables, is considered an undesirable condition in regression analysis. Although various methods exist for detecting multicollinearity, the Variance Inflation Factor (VIF) criterion is widely employed. As a general guideline, VIF values should not exceed 5 or 10 [81].

Table 7
VIF criteria results

Variable	VIF	1/VIF
Renewable energy output	1.04	0.963853
R&D expenditures	1.04	0.963853
Mean VIF	1.04	

Source: Prepared by the author as a result of the analysis.

Since the mean VIF is 1.02, it has been determined that there is no MDB problem. According to the findings obtained from the tests carried out, the model. It has been understood that it is a one-way random effects model with only a unit effect, follows a normal distribution, and does not contain a multicollinearity problem. On the other hand, the test results of the basic assumptions are in the model; revealed that heteroscedasticity, autocorrelation, and inter-unit correlation exist all three. Finally, the final analysis was made with the help of the Driscoll-Kraay regression model.

To begin, it is acknowledged that the model is often significant at the 95% confidence level when the Wald Test probability value is assessed. This is since the model has a high correlation with the data. At the same time, it can be observed that

both the parameters of the independent variables and the parameter for the constant are significant at the 95% confidence level. R^2 is around 15%, which is the significance coefficient. Together with the explanatory variables in the model, the renewable energy production in these countries does not adequately explain the economic growth of these countries. R&D expenditures in these countries are meaningful in explaining economic growth. The rho, which is the share of the variance of the unit effect in the total variance, is at the level of 88%, indicating the existence of the unit effect as an a priori indicator.

Table 8
Driscoll-Kraay Estimator

R^2	Number of Observations	Wald Test	rho	prob
0.1461	80	40.81	0.8838566	prob>0.0000
GDP	Coefficient Values	Resistive Standard Errors	T statistics	P> t
Renewable energy output	0.0082574	0.0050572	1.63	0.119
R&D expenditures	1.416107	0.2646568	5.35	0.000
Fixed Coefficient	7.594785	0.6260929	12.13	0.000

Source: Prepared by the author as a result of the analysis.

It is sufficient to explain economic growth of 1.5% if there is a 1% increase in spending on R&D. This relationship can indeed be considered because of the need for countries to increase their R&D expenditures to achieve economic growth. The fact that R^2 , which is the uncertainty coefficient, is reasonable, but relatively low (about 15%) is since different variables other than renewable energy production and R&D expenditures are also related to economic growth.

5 Discussions and Conclusions

This study was compared with previous articles in the literature. The fact that there is a positive and statistically significant relationship between these variables [62, 66, 68], in studies focusing on R&D and economic growth in the context of BRICS countries in the literature, is similar to the results of our study. According to the findings of a study conducted by Yıldız [70], using annualized data from 2000-2012, it has been shown that the effect of R&D, as well as innovation on the growth of the economy in BRICS-TM countries is both positive and statistically significant.

However, as a result of the study by Özek [72], which investigated the effect of R&D expenditures on economic development in BRICS-T countries using annual data between 2003 and 2017, it was determined that R&D expenditures only have an effect on economic growth in the long run. As a result of the study carried out by Bayraktar et al. [71] on the basis of data for the years 2000-2018, it was found

that there is a causal link operating in both directions between R&D expenditures and economic growth in BRICS-T countries. Therefore, it can be said that the findings obtained as a result of our research are similar to the findings in the literature.

Despite this, there was not found to be a significant correlation between the quantity of energy generated from renewable sources and the expansion of the economy. It should be noted that contrary to the result we obtained, in the study by Ummalla et al. [60] using panel ARDL and panel quantitative regression model, it was revealed that hydroelectric energy consumption has a significant positive effect on the economic growth of BRICS countries.

A study by Apergis and Payne [46] examined the relationship between renewable energy consumption and economic growth in a multivariate framework for a panel of twenty OECD countries during 1985 to 2005. Granger causality results show that there is bidirectional causality between renewable energy consumption and economic growth in both the short and long run. In a study conducted by Apergis and Payne [82], the relationship between renewable and non-renewable energy consumption and economic growth during 1990 to 2007, was analyzed, by panel analysis. As a result of the study, it was found that there is bidirectional causality between renewable and non-renewable energy consumption and economic growth in the short and long term. Al-Mulali et al. [83] found that 79% of countries have a positive, bidirectional long-term relationship between renewable energy consumption and GDP growth. According to Zafar et al. [84] analyzed energy, the relationship between non-renewable and renewable energy consumption and economic growth, based on the data of the Asia-Pacific Economic Cooperation (APEC) countries for the period 1990-2015.

The research reveals a strong and positive correlation between R&D spending and economic growth in BRICS countries. This indicates that technological investments in renewable energy production can indirectly contribute to economic growth. Therefore, the following points should be considered:

- Brazil, with its strong hydroelectric potential but facing risks due to climate change and dependence on water resources, is advised to increase investments in solar and wind energy and redirect R&D spending towards renewable energy technologies and energy storage solutions.
- Russia, where fossil fuel dependence supports economic growth in the short term but is not sustainable in the long term, could support pilot projects and R&D efforts in wind and solar energy. Furthermore, it is recommended that Russia increase its renewable energy investments with private sector incentives and accelerate technology transfer.
- China, with its high renewable energy and R&D capacity and strong correlation between technological innovation and economic growth, is

advised to prioritize investments in advanced energy technologies (e.g., storage, smart grids) and export-oriented projects.

- Given the environmental risks posed by a coal-dominated energy profile and the low renewable energy capacity in the Republic of South Africa, it is suggested that the country offer special financial incentives for R&D in renewable energy projects.

Taking all this into account, the following can be suggested for BRICS countries:

- To increase the contribution of renewable energy production to economic growth, countries should direct R&D investments towards energy technologies
- Each country should diversify its renewable energy sources, taking into account its current energy dependency profile
- While renewable energy investments may not directly impact economic growth in the short term, they can support growth in the long term through technological infrastructure and innovation.

In particular, the events of today served to bring to everyone's attention how significant it is for a nation's energy dependency. In this light, it is essential that every nation have an enough quantity of energy resources to meet both its own demand and that of the rest of the world. Obviously, this is a more dependable strategy when used to sources of renewable energy as opposed to those of depletable resources. The availability of energy resources has a significant bearing on the rate of economic expansion in the nation. Consumption of renewable energy may also be acquired within the budget that is allotted by a government for R&D expenses. Within this framework, the research investigates how the production of renewable energy influences economic development from the point of view of the renewable energy policies of BRICS nations within the setting of the renewable energy industry.

To determine the extent of the connection between renewable energy sources and R&D expenditures, the study additionally considers spending on R&D on a per-person basis. In this regard, the study was carried out using the data of the BRICS nations between the years of 1996 and 2015. A relevant conclusion may be drawn from combining the findings of the Panel analysis with the Driscoll-Kraay Estimator.

It was discovered that there is a considerable connection between economic growth and the amount of money spent on R&D in the BRICS nations. It can be observed because of the correlation connection that the link between economic growth and R&D data in BRICS nations is at a highly robust level. This can be said since the correlation level is quite high.

In conclusion, the findings of this study strongly support endogenous and Schumpeterian growth approaches. The weak impact of renewable energy

production on economic growth in BRICS countries can be explained by the fact that technological progress in these countries has not yet reached a level that would directly trigger growth through renewable energy investments. This limited impact of renewable energy on economic growth is consistent with the predictions of neoclassical and energy-based growth models. In contrast, the strong and significant relationship between R&D expenditures and economic growth supports knowledge-based growth approaches. Specifically, the strong and significant relationship found between per capita R&D expenditures and economic growth in BRICS countries is highly consistent with the predictions of endogenous growth theories. This is because the development of renewable energy technologies is largely linked to R&D activities.

However, the contribution of these technologies to economic growth often appears with a delay. Therefore, despite the strong impact of R&D expenditures on growth, the limited short-term impact of renewable energy is consistent with the Schumpeterian growth approach.

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