Scientific Annals of Economics and Business
72 (1), 2025, 1-19
DOI: 10.47743/saeb-2025-0002

Effects of Economic Growth and Energy Consumptions on Environmental Degradation within the Framework of LCC Hypothesis in BRICS Countries

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Abstract: The purpose of this study is to analyze the effects of economic growth, nuclear energy consumption, renewable energy consumption, and hydropower energy consumption on environmental degradation within the framework of the LCC Hypothesis in BRICS countries during the period of 1993-2022. This study aims to make a significant contribution to the literature by simultaneously discussing the effects of hydropower, nuclear, and renewable energy consumption on the load capacity factor in addition to the LCC Hypothesis for the BRICS countries for the first time. Due to the autocorrelation and heteroscedasticity problem, the FGLS (Feasible Generalized Least Square) method was used in the estimated model. According to empirical findings, the LCC hypothesis is not valid in the sample group countries. It was determined that hydropower energy consumption increases the load capacity factor, whereas nuclear energy consumption decreases the load capacity factor. No relationship was found between renewable energy consumption and the load capacity factor. These findings provide important information about the effects of energy consumption strategies of BRICS countries on environmental sustainability.

Keywords: LCC hypothesis; nuclear energy consumption; renewable energy consumption; hydropower energy consumption; economic growth.

JEL classification: Q42; Q43; Q56; O44; C51.

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Article history: Received 15 July 2024 | Accepted 19 December 2024 | Published online 17 March 2025

To cite this article: Uçar, M., Ülger, M., Atamer, M. A. (2025). Effects of Economic Growth and Energy Consumptions on Environmental Degradation within the Framework of LCC Hypothesis in BRICS Countries. *Scientific Annals of Economics and Business*, 72(1), 1-19. https://doi.org/10.47743/saeb-2025-0002.

1. INTRODUCTION

One of the biggest global problems we face in today's world is climate change. This is one of the most obvious and devastating consequences of environmental degradation. The increase in greenhouse gases released into the atmosphere since the industrial revolution has caused temperatures to rise, weather events to become more frequent and severe, and sea levels to rise. These changes have disrupted the balance of ecosystems, threatened biodiversity, and created significant social and economic impacts on human societies. Human-induced activities such as deforestation, overuse of fossil fuels, and unsustainable agricultural practices accelerate climate change and further deepen environmental degradation by destroying natural habitats.

Therefore, in efforts to combat climate change and ensure environmental sustainability, nuclear energy, despite its low carbon emission advantages, appears to be an energy source that needs to be carefully evaluated with problems such as radioactive waste management and environmental degradation. Although nuclear energy offers the potential to produce energy with low carbon emissions, it also brings serious environmental and health problems, such as radioactive waste management and environmental degradation. In addition, it is a renewable option that emits fewer and more efficient emissions. The potential to produce energy with low carbon emissions reduces dependence on fossil fuels and plays an important role in combating environmental degradation (Wang *et al.*, 2024a; Wang *et al.*, 2024b). Additionally, nuclear energy is considered one of the best options currently available to replace fossil fuels (Murshed *et al.*, 2022).

In the study group of BRICS countries (Brazil, Russia, India, China, South Africa), according to the World Nuclear Association (2024) data, there are 2 nuclear power plants in Brazil with a nuclear energy capacity of 1,884 MWe. The share of nuclear energy production is around 2.5%. There are 37 nuclear power plants in Russia with a nuclear energy capacity of 27,727 MWe. The share of nuclear energy production is around 19.6%. There are 22 nuclear power plants in India, with a nuclear energy capacity of 7,182 MWe. The share of nuclear energy production is around 3.1%. There are 54 nuclear power plants in China, with a nuclear energy capacity of 52,181 MWe. The share of nuclear energy production is around 5%. There are two nuclear power plants in South Africa with nuclear energy capacities of 1,854 MWe. The share of nuclear energy production is around 4.9%. Among the BRICS countries, China has the largest nuclear energy capacity. There are 117 nuclear power plants operating in 5 countries with nuclear energy capacities of 90,828 MWe.

Figure no. 1 illustrates the change in nuclear energy consumption by the BRICS countries over time between 1993 and 2022. It is seen that nuclear energy consumption is highest in Russia. Compared with other countries, the nuclear energy consumption of Russia and China was increased rapidly. On the other hand, although there is not much change in Brazil and India, nuclear energy consumption was decreased in South Africa.

Hydropower energy, as a renewable and clean energy source, also plays an important role in preventing environmental degradation by reducing dependence on fossil fuels and reducing greenhouse gas emissions. As a renewable and clean energy source, hydropower energy plays an important role in reducing greenhouse gas emissions and preventing environmental degradation by reducing our dependence on fossil fuels. In the study, according to IHA (2024) data, considering the BRICS countries in terms of hydropower energy, which is a clean energy source, Brazil has 109 GW, Russia has over 55 GW, India has 51 GW, and China has over 414 GW. China is a world leader in hydropower energy production. South Africa has a 3 GW hydropower energy capacity.

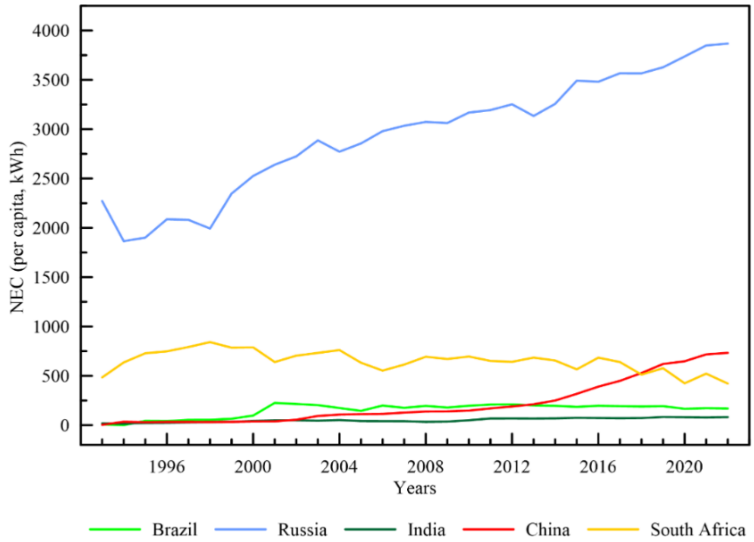

Figure no. 1 – BRICS countries' nuclear energy consumption (per capita, kWh)

Figure no. 2 illustrates the change in hydropower energy consumption of the BRICS countries over time between 1993 and 2022. It can be seen that hydropower energy consumption is highest in Brazil. Compared with other countries, China's hydropower energy consumption was increased rapidly. On the other hand, although there is not much change in South Africa and India, hydropower energy consumption is low. There have been significant ups and downs in hydropower energy consumption in Brazil and Russia.

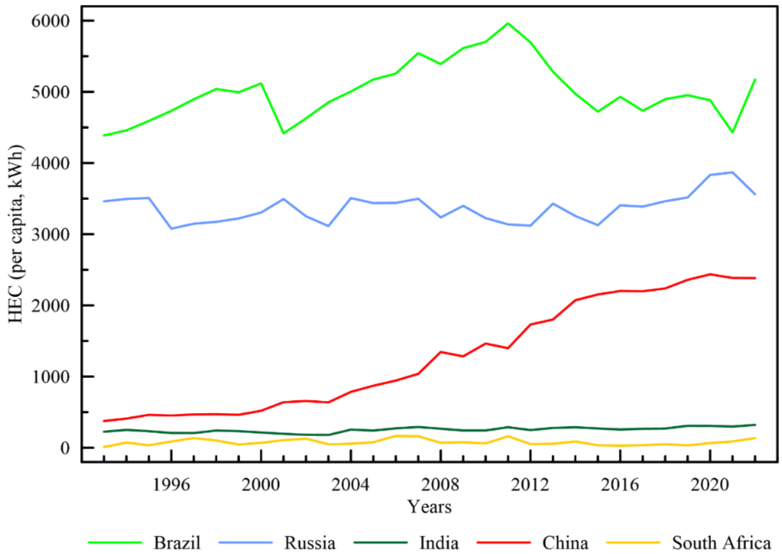

Figure no. 2 – BRICS countries' hydropower energy consumption (per capita, kWh)

Given their impact on reducing dependence on fossil fuels and greenhouse gas emissions, renewable energy sources such as hydropower energy are of critical importance in preventing environmental degradation and building a sustainable future. Renewable energy sources reduce greenhouse gas emissions by reducing dependence on fossil fuels, and they contribute to a sustainable future by preventing environmental degradation. In this context, renewable energy sources are seen as potential solutions to energy security and climate change problems (Doğan *et al.*, 2021).

Figure no. 3 illustrates the change in renewable energy consumption of the BRICS countries over time between 1993 and 2022. It is seen that renewable energy consumption is highest in Brazil. Compared with other countries, renewable energy consumption by Brazil and China was increased rapidly. On the other hand, although there is not much change in South Africa and India, renewable energy consumption is seen to be low. In this context, there has not been much change in Russia's renewable energy consumption.

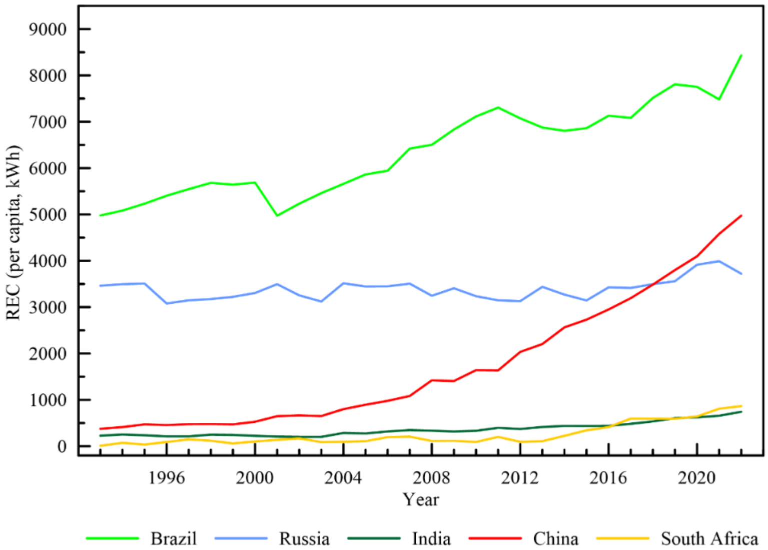

Figure no. 3 – BRICS countries' renewable energy consumption (per capita, kWh)

The ecological footprint, an indicator of environmental degradation, only shows how humans meet the need for natural resources and nature's biological capacity. An indicator showing the supply and demand sides of nature could provide a better analysis of environmental quality. In this case, the Load Capacity Factor (LCF) was proposed by Siche *et al.* (2010) to improve environmental assessment. Figure no. 4 shows the LCF indicator trends of the BRICS countries over time from 1993 to 2022. This demonstrates how a state can sustain its population according to its current lifestyle. Biocapacity and ecological footprint are used to measure LCF. LCF is measured by dividing incapacity by ecological footprint. Whereas the value of LCF is "1" or higher, it indicates that current environmental conditions are sustainable; A value below "1" indicates that environmental degradation is unacceptable. When compared among countries, it can be seen that Brazil has the best LCF. Although Russia was close to 1 in the reference period, it did not fall below 1. It is also in a better situation than other countries. In addition, India, South Africa, and China are below the sustainability limit, indicates that current environmental conditions are not sustainable. Environmental degradation was increased over the years.

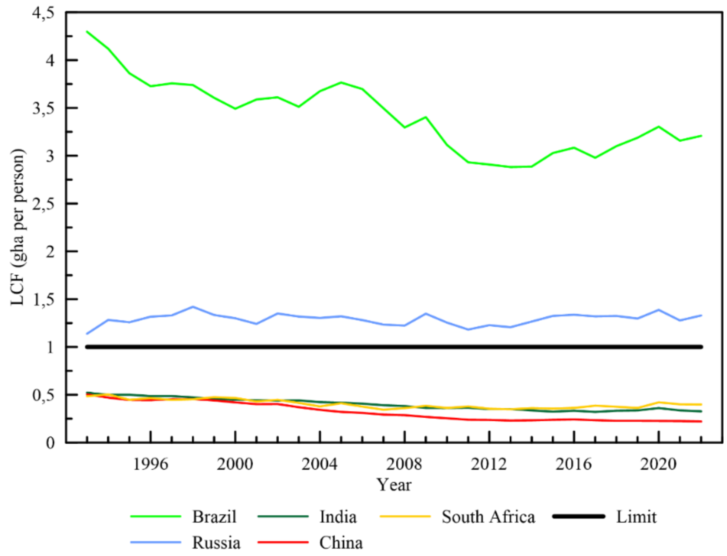

Figure no. 4 – BRICS countries' load capacity factor (gha per person)

Economic growth increases the welfare of societies, but it results in the overuse of natural resources and environmental degradation. One of the most frequently used theories developed by Grossman and Krueger (1991) to explain the relationship between economic growth and environmental quality is the Environmental Kuznets Curve (EKC). Empirical research shows for the first time that an inverted U-shaped non-linear relationship between economic growth and environmental quality (Wang *et al.*, 2023).

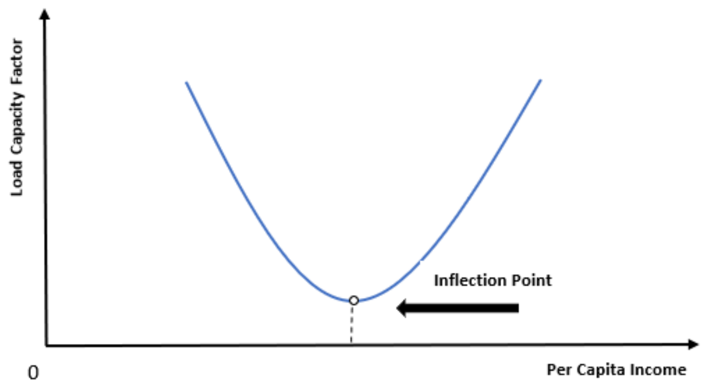

Figure no. 5 – Load Capacity Curve

Another theory to describe the relationship between economic growth and environmental quality is the Load Capacity Curve (LCC) hypothesis. This hypothesis (Figure no. 5) states that economic growth positively affects environmental quality up to a certain point. Once this point has been reached, further economic growth will reduce environmental quality. It shows that there is a U-shaped non-linear relationship between economic growth and load capacity factor (Pata and Tanriover, 2023). The EKC and LCC hypotheses provide insight into this relationship while explaining the relationship between economic growth and environmental quality. (Wang *et al.*, 2024a; Wang *et al.*, 2024b).

The main purpose of this study is to analyze the effects of economic growth, nuclear energy consumption, renewable energy consumption, and hydropower energy consumption on environmental degradation in BRICS countries within the framework of the LCC hypothesis for the period of 1993-2022. Based on this purpose of the study, it was possible to present some hypotheses.

H1: The LCC hypothesis is valid in BRICS countries.

H2: Nuclear energy consumption reduces the LCF.

H3: Hydropower energy consumption will increase the LCF.

H4: Renewable energy consumption will increase the LCF.

There are many important reasons why BRICS countries are preferred to measure renewable energy consumption, hydropower energy consumption, and nuclear energy consumption. These countries play an important role in world energy markets because of their rapid economic growth and increasing demand for energy. The diversity of BRICS countries' energy production and consumption is demonstrated by China's large-scale nuclear energy investments, Brazil's leadership in hydropower energy generation, and India's rapid expansion of renewable energy capacity. These countries were seek sustainable energy solutions because of their high greenhouse gas emissions and environmental degradation. The energy consumption patterns of the BRICS countries should be examined at both regional and global levels because of their efforts to create energy security, sustainability, and innovative policies. Therefore, it offers important insights into global energy policies and sustainable strategies for BRICS countries.

It is expected that this study will contribute to the literature by simultaneously discussing the effects of hydropower, nuclear, and renewable energy consumption on the load capacity factor in addition to the LCC hypothesis for the BRICS countries for the first time. This study has a limitation regarding the reference period. The absence of China's pre-1993 nuclear energy data and Russia's pre-1992 incapacity and ecological footprint data caused this study to determine the years 1993-2022 as the reference period.

In the second section of the study, the literature section is included. In the third section, the model, data, method, and empirical findings are discussed. The fourth section concludes with the concluding remarks and policy recommendations.

2. LITERATURE REVIEW

Although there was not many studies investigated the validity of the LCC hypothesis, it has become a popular research topic recently. Based on the literature review, the variables used in studies testing the validity of the LCC hypothesis differ. It is also possible to say that because of the research conducted, no general conclusions can be reached in the literature. Note that although most of the results show that the LCC hypothesis is valid, some studies conclude that the LCC hypothesis is not valid. While examining the literature section in this study, studies that accept the validity of the LCC hypothesis and those that argue that the LCC hypothesis is not valid were evaluated separately. Again, while these studies were considered, studies conducted in a single country or country group were evaluated separately. Studies conducted on the BRICS countries are also included.

2.1 Studies Finding the LCC Hypothesis Valid

Within the studies supporting the LCC hypothesis, some have analyzed a single country. Güneysu (2023) investigated data between 1970 and 2018 for the Turkey economy using FMOLS and DOLS analyses, and Bozatli and Akca (2024) examined the period of 1990-2020 for the Turkey economy using ARDL analysis. Another study examining Turkey was conducted by Çamkaya (2024) using data covering the years 1961-2022 with ADF, ADL, and FMOLS analyses. Although the periods analyzed in all of these studies conducted for the Turkey economy differ, it is concluded that the LCC hypothesis is valid for Turkey.

Examples of single-country analyses can be given by Huang *et al.* (2023), which examines the 1975-2021 period for the Indian economy, and Pata and Kartal (2023), which examined the South Korean economy with data from the 1977-2018 period. ARDL analysis was used in both studies, and both studies concluded that the LCC hypothesis is valid. Additionally, Apergis *et al.* (2023) tested data from 1980 to 2015 in the United States using the Fourier estimator and again concluded that the LCC hypothesis is valid. Hakkak *et al.* (2023) analyzed data for the Russian economy between 1992 and 2018 using the ARDL method and stated that the LCC hypothesis is valid.

Studies supporting the LCC hypothesis are not limited to only one country. There are also studies conducted as a country group. Dogan and Pata (2022) examined the period of 1986-2017 for G7 countries. Dai *et al.* (2024) tested data for ASEAN countries from 1986 to 2018. The CS-ARDL method was used in both studies, and both studies found that the LCC hypothesis was valid. Wu *et al.* (2024) and Feng *et al.* (2024) analyzed the data between 1996 and 2019 using the QR (Panel quantile regression) method for the E7 countries and found results that support the LCC hypothesis. investigated the impact of economic policy uncertainty and renewable energy on environmental quality; Feng *et al.* (2024) included technological innovation as a variable in their analysis. Afshan and Yaqoob (2023) conducted an MMQR (Moment quantile regression) analysis using data between 2000 and 2018 for China, Brazil, Mexico, India, and Turkey. Guloglu *et al.* (2023) tested the period 1980-2018 for 26 OECD countries using QMG Estimator. Both studies concluded that the LCC hypothesis is valid. Wang *et al.* (2024a); Wang *et al.* (2024b) analyzed the data of 5 selected Asian countries between 1990 and 2020 using the panel quantile regression technique and stated that the LCC hypothesis is valid.

Caglar *et al.* (2024) analyzed the relationship between competitive industrial performance, renewable energy, urbanization, and the load capacity factor of BRICS countries. For this purpose, the period 1990-2018 was used. They used the CUP-FM and CUP-BC models in their analysis and stated that the LCC hypothesis was valid. Li *et al.* (2024) analyzed the same year's data for BRICS economies through CS-ARDL and obtained different results because the variables they used were different. They also stated that the LCC hypothesis was valid. In addition, financial development, economic growth, and non-renewable energy negatively affect ecological quality; They stated that renewable energy positively affects ecological quality. Yang *et al.* (2024) and S. Wang *et al.* (2024); W. Wang *et al.* (2024) examined the BRICS countries for the same period. Yang *et al.* (2024) conducted an MMQR analysis and found that natural resources, social globalization, and GDP negatively affect ecological quality, whereas biomass energy negatively affects ecological quality. S. Wang *et al.* (2024); W. Wang *et al.* (2024) stated that financial development is negatively related to the load capacity factor, whereas there is a positive relationship between financial development and carbon emissions. In addition, according to their results, economic growth decreases the load capacity factor. In addition to these results, two studies found that the LCC hypothesis is valid.

2.2 Studies Finding that the LCC Hypothesis is not Valid

Although many studies in the literature accept the LCC hypothesis as valid, a few also conclude that the LCC hypothesis is not valid.

Pata and Tanriover (2023) analyzed the period 2004-2018 for the 10 countries that most tourists visit, and Deng *et al.* (2024) selected 9 countries (China, Germany, India, Japan, South Africa, South Korea, Russia, the United States). They analyzed data from 1998 to 2018 for the Kingdom of Saudi Arabia and the United States. The CS-ARDL method was used in both studies, and both studies concluded that the LCC hypothesis was not valid. Pata *et al.* (2023) analyzed data covering the period of 1974-2018 for the German economy using the Fourier ARDL method and stated that the LCC hypothesis is not valid. Yang *et al.* (2023) tested the LCC hypothesis in BRICS countries using the CS-ARDL method during the period 1990-2018 and found that the LCC hypothesis is not valid. addition, because of their analysis, they concluded that while economic development, financial development, and natural resources reduce ecological quality, renewable energy increases environmental quality. Shahzad *et al.* (2024) analyzed the 2000-2020 period for the 20 most visited countries using panel GMM and panel quantile regression models. Ulussever *et al.* (2024) tested the data between 2000 and 2019 using the AMG method for GCC countries (Gulf Cooperation Council countries). Both studies rejected the LCC hypothesis was invalid. Another study, which reached the same conclusion as these studies and found the LCC hypothesis invalid, was conducted by Erdogan (2024) using FMOLS and DOLS methods for 13 African countries with data covering the period of 1992-2020.

2.3 Relationship between Nuclear Energy Consumption and LCF

This part of the literature covers the studies analyzing the relationship between nuclear energy consumption and load capacity factor. When the literature is analyzed, it is generally concluded that nuclear energy consumption supports environmental development by increasing the load capacity factor.

An example of time series studies is the study conducted by Pata and Samour (2022) using Fourier analysis with data for the period 1977-2017 for the French economy. Pata and Samour (2022) stated that nuclear energy increases the load capacity factor by reducing carbon emissions. In addition, Hakkak *et al.* (2023) determined that nuclear energy increases the load capacity factor as a result of ARDL analysis with data for Russia between 1992-2018.

Another time series study was conducted by Raihan (2024). In his study, Raihan (2024) examined the Indian economy for the period 1070-2022 and used DOLS analysis. As a result of his studies, he stated that nuclear energy increased the load capacity factor. Özkan *et al.* (2024) analyzed the Pakistani economy for the period 1971-2021, and Jin *et al.* (2024) analyzed the German economy for the period 1974-2018 using the ARDL method. Both studies concluded that nuclear energy increases the load capacity factor.

There are also panel studies examining the relationship between nuclear energy and load capacity. Aydin (2024) analyzed the economies of 8 countries with panel causality analysis using data between 1993-2018 and found a bidirectional causality relationship between the variables. Ozcan *et al.* (2024), on the other hand, analyzed the data covering 8 countries between the first quarter of 1995 and the last quarter of 2018 with a non-linear quantile approach and concluded that nuclear energy increases load capacity.

Another example of panel studies is the study conducted by Teng *et al.* (2024) with data covering the period 1990-2021 for the economies of 5 countries. Teng *et al.* (2024) concluded that nuclear energy increases the load capacity factor as a result of their CS-ARDL analysis. Another study reaching the same conclusion was conducted by Islam *et al.* (2024). Islam *et al.* (2024) analysed the economies of 10 countries for the period 1990-2020 with DOLS analysis and reached the same conclusion.

2.4 Relationship between Renewable Energy Consumption and LCF

In this part of the literature, the relationship between renewable energy consumption and load capacity factor is analyzed. While some of the studies have found that renewable energy consumption increases the load capacity, some studies have found that renewable energy consumption decreases the load capacity factor. In addition, there are also studies indicating that renewable energy consumption has no effect on the load capacity factor.

An example of time series studies is the study by Xu *et al.* (2022). Xu *et al.* (2022) analyzed Brazilian data for the period 1970-2017 using the ARDL method and found that renewable energy consumption decreases the load capacity factor. Hakkak *et al.* (2023) analyzed the Russian economy for the period 1992-2018, again using the ARDL method, and concluded that renewable energy consumption increases the load capacity factor.

Another example of time series studies is the study conducted by Jin *et al.* (2024) for the German economy for the period 1974-2018. Jin *et al.* (2024) concluded that renewable energy consumption increases the load capacity factor as a result of their tests using the ARDL method. Pata and Kartal (2023) analyzed the data of South Korea between 1977-2018 with the ARDL method and concluded that renewable energy consumption does not affect the load capacity factor in the long run. In the study examining the causality relationship between renewable energy consumption and load capacity factor, Pata *et al.* (2024) used Fourier causality analysis and found a bidirectional causality between the variables.

There are also panel studies examining the relationship between renewable energy consumption and load capacity factor. Shang *et al.* (2022) analyzed the data covering the period 1980-2018 for ASEAN countries with ARDL method, Sun *et al.* (2024) analyzed the period 1990-2019 for 17 APEC countries with second generation panel data analysis. In addition, Islam *et al.* (2024) analyzed the data covering the period 1990-2020 for 10 countries with the DOLS method. All of these studies have found that renewable energy consumption leads to environmental improvement by increasing load capacity.

2.5 Relationship between Hydropower Energy Consumption and LCF

Studies examining the relationship between hydropower energy consumption and load capacity factor are not very common in the literature. The rare study on this subject was conducted by Ozcan *et al.* (2024). They analyzed a panel of 8 country economies using data from the first quarter of 1995 to the last quarter of 2018 using the non-linear quantile approach. As a result of their analysis, they concluded that hydropower energy consumption reduces the load capacity factor.

3. MODEL AND DATA, METHOD, AND EMPIRICAL FINDINGS

3.1 Model and Data Definition

This study aims to investigate the effects of economic growth, nuclear energy consumption, renewable energy consumption, and hydropower energy consumption on environmental quality in BRICS countries within the framework of the LCC hypothesis. The empirical analysis period of this study consists of annual data from 1993 to 2022. In this context, Table no. 1 presents the variables used in the model.

Table no. 1 – Variables

Variables	Explanation	Reference
Hydropower energy consumption (LogHE)	Hydropower energy consumption per capita - Measured in kilowatt-hours per capita.	Our World in Data (2024)
Nuclear energy consumption (LogNE)	Nuclear energy consumption per capita - Measured in kilowatt-hours per capita.	Our World in Data (2024)
Renewable energy consumption (LogRE)	Renewable energy consumption per capita - Measured in kilowatt-hours per capita.	Our World in Data (2024)
Load Capacity Factor (LCF) (LogLCF)	Biocapacity/ecological footprint (gha per person)	Global Footprint Network (GFN)
Economic Growth (LogGDppc)	GDP per capita (constant 2015 US$)	WDI

The model used in the study is as follows:

$$LogLCF_{i,t} = \beta_0 + \beta_1 LogGDPpc_{i,t} + \beta_2 LogGDPpc_{i,t}^2 + \beta_3 LogHE_{i,t} + \beta_4 LogNE_{i,t} + \beta_5 LogRE_{i,t} + u_{i,t} \tag{1}$$

Logarithmic transformations of the variables included in the model were used. The use of logarithmic transformations of variables in econometric analysis offers many advantages from both theoretical and practical perspectives. Logarithmic transformation allows to analyze the proportional changes of variables. Logarithmic transformation reduces the impact of extreme outliers by normalizing the distribution of the data. Economic data can often have a positively skewed (right-skewed) distribution. Logarithmic transformation reduces such skewness, making regression results more reliable and stable (Gujarati and Porter, 2009; Greene, 2012; Wooldridge, 2016).

3.2 Method and Empirical Results

This section provides theoretical explanations of the methodology and empirical findings. Table no. 2 shows summary statistics of the variables.

Table no. 2 – The Summary Statistics of Variables

Variable	Observation	Mean	Std.Dev.	Min.	Max.
LogLCF	150	-0.1332373	0.4033167	-0.6556186	0.6331076
LogGDPpc	150	3.629579	0.3567486	2.748807	4.062967
LogGDPpc2	150	13.30026	2.464548	7.555939	16.5077
LogHE	150	2.895008	0.7242378	1.006552	3.775407
LogNE	150	2.412502	0.7275777	-0.0136762	3.587408
LogRE	150	3.03159	0.6529647	1.006552	3.925882

The summary statistics table shows that the number of observations is 150. This is a sufficient number for the application of panel data analysis. It can also be seen that the variables do not deviate significantly from the LogLCF mean. The deviation of this variable from the mean may indicate the presence of outliers in the data set. For example, in some periods or situations the measured variable may have exceptionally high or low values. It is also possible that some variables are naturally widely distributed. For example, the diversity of economic indicators across countries in terms of their size. Table no. 3 shows the test statistics needed to decide on the model to be estimated in the study.

Table no. 3 – The Selection of Model

Model	F-Test		Hausman Test		Decided Model
	Stats.	p-value	Stats.	p-value	
(Dep. Variable LogLCF)	3539.46	0.000***	142.59	0.000***	Fix Effect Model

Note: *** stands for significance at 1% level of significance.

The table shows that the model has a unit effect. The Hausman test shows that the appropriate model is the Fixed Effects Model. According to this result, it was decided that the coefficient estimator to be used would be based on the Fixed Effects Model. After the model was decided, autocorrelation, heteroskedasticity and cross-sectional dependency were investigated.

Wald test was used to examine the heteroscedasticity problem. The test calculates a Wald statistic for heteroscedasticity. The test tests the hypothesis sigma^2(i)==sigma for i=1, N_g. N_g represents the number of cross-section units in the hypothesis. The calculated test statistic is distributed as Chi square (N_g) under the homoscedasticity null hypothesis (Greene, 2012). The presence of heteroscedasticity can lead to biased results in the calculation of coefficients and standard errors for t-values. In such a case, OLS estimates may not be biased and inconsistencies in standard errors may also be encountered (Yaqub *et al.*, 2015). The test developed by Wooldridge (2010) was used to investigate whether the model contained autocorrelation. This test is used to detect serial correlation in the unique errors of a linear panel-data model. Drukker (2003) presented simulation evidence showing that this test has more consistent properties for reasonable sample sizes.

Cross-sectional dependence has an important place in panel data analysis. Determining cross-sectional dependence is important for determining the coefficient estimator. To investigate cross-sectional dependence, the CDLM test was used in the study (Breusch and Pagan, 1980). This test is obtained from the squares of the "pair-wise" type correlation coefficients of the error terms. In addition, it gives effective results in cases where the cross-sectional dimension (N) is smaller than the time dimension (T) (N<T) (Pesaran, 2021). The equation used to calculate the test is as follows;

$$CD_{LM} = T\sum_{i=1}^{N-1}\sum_{j=i+1}^{N} T\hat{p}_{ij}^{2} \quad (2)$$

P_{ij} in the equation represents the sample estimate for the "pair-wise" type correlation coefficients of the error terms.

In line with theoretical explanations, Table no. 4 shows the test results of autocorrelation and heteroskedasticity, as well as cross-sectional dependence of the model used in the study.

Table no. 4 – Autocorrelation, Heteroscedasticity and CD Tests

Model	**Wooldridge Test Correlation**		**Modified Wald test for groupwise heteroskedasticity**		**CD Test**		
	Wooldridge Test		Modifiye Wald Test		Test	Stat.	P-val.
					LM	10.86	0.368
	F(1,5)	9.448	$x^2(5)$	27.70	LMadj	-0.2736	0.784
	p-değ>F	0.037	p-değ<x^2	0.000	LMCD	-0.4423	0.658

In the table, autocorrelation and heteroscedasticity test statistics are significant at 5% and 1% significance level, respectively. These results show that the null hypotheses are rejected. In this context, it was concluded that the model contains both autocorrelation and heteroskedasticity. According to the CD test results, the null hypothesis was accepted, and it was concluded that the model did not contain cross-sectional dependence.

Since the model does not include cross-sectional dependence, the first-generation panel unit root test, LLC (Levin *et al.*, 2002), was used. This test allows different unit root tests to be applied for each cross-section and thus has the feature of being a more powerful panel unit root test. While the null hypothesis of the test states that the series contain unit roots, the alternative hypothesis is that the series are stationary (Baltagi, 2005). The basic equation used in calculating the test is as follows;

$$\Delta Y_{it} = pY_{it-1} + \sum_{L=1}^{p_i}\theta_{iL}\Delta Y_{it-L} + \alpha_{mi}d_{mt} + u_{it} \quad (3)$$

Table no. 5 shows the LLC unit root test results. As seen in Table no. 4, the model does not include cross-sectional dependency. Therefore, LLC, the first-generation panel unit root test, was used.

Table no. 5 – Unit Root Test

Variable	Constant Adjusted t (p-value)	Constant+Trend Adjusted t (p-value)
LogLCF	-1.334 (0.091*)	0.875 (0.809)
d. LogLCF	-4.486 (0.000***)	-3.155 (0.00***)
LogGDPpc	-1.908 (0.028**)	2.764 (0.997)
LogGDPpc2	-1.280 (0.100)	2.410 (0.992)
d.LogGDPpc2	-2.103 (0.017**)	-1.409 (0.080*)
LogHE	-0.969 (0.166)	0.016 (0.506)
d.LogHE	-4.023 (0.000***)	-2.589 (0.004***)
LogNE	-3.508 (0.000***)	-5.698 (0.000***)
LogRE	1.721 (0.957)	-1.026 (0.152)
d.LogRE	-3.952 (0.000***)	-2.794 (0.002**)

Note: The delay length is set to 1. *, **, *** indicate significance at 10%, 5% and 1% significance level, respectively.

Table no. 5 shows the test statistics of the stationarity test for both constant and constant and trend options. According to the stationarity test results, three variables are stationary at the I(1) level, while the other three variables are stationary at the level. In this context, it has been observed that there is no stationarity problem of the variables. For the estimator to be used in the study, it is important that the variables become stationary, not their stationarity levels. In this context, it was concluded that the necessary condition for the estimator was met.

Since the estimated model had autocorrelation and heteroscedasticity problems, it was decided to use FGLS (Feasible Generalized Least Square), which is a robust estimator in these conditions. The classic reference work of this estimator method is Parks (1967) (Moundigbaye *et al.*, 2018). While FGLS is recommended by analyzes Taylor (1977) so that the model can be used in cases where the problem of heteroskedasticity exists, it has been tested by analyzes Rao and Griliches (1969) for cases where the model contains an autocorrelation. Reed and Ye (2011) developed a structure that simultaneously provides solutions to serial correlation and cross-sectional dependence in the error term for Ω_{NT}(Ω; error heteroskedasticity) in the FGLS estimator. They used the following equation for Ω_{NT};

$$\Omega_{NT} = \sum \otimes \Pi \tag{4}$$

The FGLS estimator ensures that asymptotically inefficient estimators provide relatively better performance in finite samples (Reed and Ye, 2011). The equations used for OLS and FGLS estimation methods for $\hat{\beta}$ and Var$(\widehat{\beta})$ are as follows (Beck and Katz, 1995):

$$\hat{\beta} = (X'\hat{\Omega}^{-1}X)^{-1}X'\hat{\Omega}^{-1}y \quad (5)$$

$$Var(\hat{\beta}) = (X'\hat{\Omega}^{-1}X)^{-1} \quad (6)$$

In the above equations, $\hat{\Omega}$; represents the assumptions that represent the cases of error heteroscedasticity, serial correlation and cross-sectional dependence.

Table no. 6 – FGLS Results

Variables	Coef.	Std. Err.	p-val.
LogGDPpc	1.322	0.495	0.008***
LogGDPpc2	-0.175	0.072	0.015**
LogHE	0.064	0.038	0.090*
LogNE	-0.034	0.014	0.016**
LogRE	-0.007	0.043	0.865
Cons.	-2.646	0.854	0.002***
Statistics of Models	Wald chi2: 37.87		
	F Value: 0.000***		

Note: ***, ** and * denote significance at 1%, 5% and 10%, respectively.

According to the statistics in Table no. 6, it was observed that only renewable energy consumption did not have a significant relationship with the dependent variable. It was concluded that a 1% increase in the growth variable increased the LCF by 1.322%. In addition, when the coefficient signs of the square of GDPpc and GDPpc are examined, it has been determined that the LLC hypothesis is not valid. A 1% increase in the LogHE variable increases the dependent variable by 0.064%. A 1% increase in the LogNE variable reduces the LCF by 0.034%. In this context, it has been observed that only the nuclear energy (LogNE) variable has a negative impact on environmental sustainability.

4. CONCLUSIONS

The study tested the LCC hypothesis of BRICS countries and investigated their environmental quality in this context. The dependent variable in the model is Load Capacity Factor (LCF), while the independent variables are economic growth, nuclear energy consumption, renewable energy consumption and hydropower energy consumption. These relationships were investigated with annual data from 1993-2022. According to empirical findings, it has been observed that the LCC Hypothesis is not valid in the sample group countries. In this case, the hypothesis "the LCC hypothesis is valid in BRICS countries." could not be confirmed. Our findings are consistent with the results of the studies by Pata and Tanriover (2023), Pata *et al.* (2023), Yang *et al.* (2023), Deng *et al.* (2024), Shahzad *et al.* (2024), Ulussever *et al.* (2024) and Erdogan (2024).

LCF is calculated as the ratio of a region's or world's capacity to produce natural resources to the resources consumed by that region or world. In this context, this phenomenon is a very important indicator for understanding nature's supply capacity and sustainability. In line with this information, the relationship between economic growth and LCF is important. In the findings, it was determined that economic growth increased LCF. This result is unexpected. Since growth generally increases the ecological footprint, its impact on environmental quality is negative. The LCF phenomenon demonstrates nature's supply capacity. The positive relationship between growth and growth is an unexpected finding. There may be possible reasons for this situation. If growth is supported by increased productivity, use of renewable energy and sustainable production methods, it can be possible to limit the increase in ecological footprint. In such a case, economic growth does not push the limits of biocapacity and may have positive effects on the Load Capacity Factor. When evaluated over the sample group, it may be due to the policies implemented by the countries in question or the relatively better condition of nature's supply capacity. Therefore, importance should be given to innovative growth strategies in order to achieve the balance between economic growth and ecological balance in sustainable development goals. The positive impact of growth on LCF can be increased through various policies such as efficient use of resources, transition to renewable energy and adoption of environmentally friendly technologies.

It has been found that hydropower consumption increases LCF. This situation confirms the hypothesis "Hydropower energy consumption will increase the LCF.". In this context, this result shows that this type of energy is an important tool for sustainable development. In order to increase the positive impact of this energy on the environment, it would be appropriate to reduce dependence on fossil fuels and encourage clean energy production by increasing the number and capacity of hydropower power plants. In addition, by increasing the efficiency of the energy produced, reducing unit energy consumption and reducing the ecological footprint will increase environmental quality. Tax reductions, subsidies and financial incentives should be provided to increase hydropower energy as well as other renewable energy investments.

It has been observed that nuclear energy consumption has a negative effect on LCF. It was predicted that this finding may be related to various environmental and social risks of this energy source. Nuclear energy production produces highly radioactive waste. These wastes are difficult to store and manage safely and pose long-term environmental risks. Therefore, it is an expected result that the impact on the environment will be negative. This situation confirms the hypothesis "Nuclear energy consumption will reduce the LCF.". Innovative and safe technologies should be developed to increase safety for the storage of radioactive waste. Additionally, the development of technologies and practices that will optimize water use of nuclear power plants and reduce thermal pollution will help create a positive impact on LCF. As an alternative policy proposal, diversity in energy production should be ensured and dependence on nuclear energy should be reduced. In this context, it is a necessity for economies to turn to more sustainable energy sources.

No relationship could be detected between renewable energy consumption and LCF. In this case, the hypothesis "Renewable energy consumption will increase the LCF." could not be confirmed. The expected potential impact of renewable energy consumption is positive. However, no relationship was found. There may be possible reasons for this situation. The production of renewable energy sources may not meet the energy consumption needs in some regions. In this case, a mismatch between energy consumption and production may occur. In addition, in this type of energy, the lack of sufficient and effective energy storage solutions to store the energy obtained from renewable energy sources may not be able to balance the fluctuations in energy supply. Another reason may be that these energy-oriented policies are missing or inadequate. In such a case, infrastructure investments should be made and network capacity should be increased to facilitate the integration of renewable energy sources into existing energy networks. Tax reductions, subsidies and other financial incentives should be provided for renewable energy investments. International collaborations should be established to facilitate technology transfer from developed countries regarding renewable energy technologies. By implementing such policies, the contribution of renewable energy consumption to environmental sustainability can be increased.

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