Sosyoekonomi

2025, Vol. 33(64), 225-260

*RESEARCH ARTICLE*

ISSN: 1305-5577
DOI: 10.17233/sosyoekonomi.2025.02.10
Date Submitted: 22.07.2024
Date Revised: 16.12.2024
Date Accepted: 14.03.2025

# The Effect of Nuclear Energy Use and Military Expenditures on The Formation of The Environmental Kuznets Curve: A Study for BRICS Countries

***Mustafa Göktuğ KAYA** (https://orcid.org/0000-0003-4124-4733), Ministry of Treasury and Finance, Türkiye; mustafa.goktug.kaya@vdk.gov.tr*

***Mehmet ÖZCAN** (https://orcid.org/0000-0001-9082-0894), Karamanoğlu Mehmetbey University, Türkiye; mehmetozcan@kmu.edu.tr*

***Bilge AFŞAR** (https://orcid.org/0000-0002-2891-7617), KTO Karatay University, Türkiye; bilge.afsar@karatay.edu.tr*

***Yiğit YILDIZ** (https://orcid.org/0000-0001-7797-8240), Ministry of Treasury and Finance, Türkiye; yigit.yildiz@vdk.gov.tr*

## Nükleer Enerji Kullanımı ve Askeri Harcamaların Çevresel Kuznets Eğrisinin Şekline Etkisi: BRICS Ülkeleri Üzerine Bir Araştırma

### Abstract

The Environmental Kuznets Model examines the relationship between per capita income level and environmental quality. This study aims to estimate the current Environmental Kuznets Curve (EKC) model, which considers military expenditures and foreign direct investments in Brazil, China, India, Russia, and South Africa, with a focus on countries that produce nuclear energy. In this regard, the data for these countries from 1992 to 2020 were subjected to econometric analysis. Three control variables -carbon emissions per capita, GDP per capita, and the share of nuclear energy in total energy consumption -were used in the econometric model. According to the findings, the EKC in these countries is U-shaped. The study also aims to fill the gap in the literature by estimating the EKC model that considers the military expenditures and foreign direct investments of countries producing nuclear energy.

**Keywords** : The Environmental Kuznets Curve (EKC), BRICS, Military Expenditures, Nuclear Energy, Foreign Direct Investment.

**JEL Classification Codes** : C33, Q53, Q56.

### Öz

Çevresel Kuznets Modeli, kişi başına düşen gelir düzeyi ile çevre kalitesi arasındaki ilişkiyi incelemektedir. Bu çalışma, nükleer enerji üretebilen Brezilya, Çin, Hindistan, Rusya ve Güney Afrika'nın askeri harcamalarını ve doğrudan yabancı yatırımlarını dikkate alan güncel Çevresel Kuznets Eğrisi modelini tahmin etmeyi amaçlamaktadır. Bu doğrultuda söz konusu ülkelerin 1992-2020 dönemine ait verileri ekonometrik analize tabi tutulmuştur. Ekonometrik modellemede kişi başına karbon emisyonu, kişi başına GSYİH ve nükleer enerjinin toplam enerji tüketimindeki payı olmak üzere üç kontrol değişkeni kullanılmıştır. Bulgulara göre, bu ülkelerdeki Çevresel Kuznets Eğrisi "U" şeklindedir. Çalışma ayrıca nükleer enerji üreten ülkelerin askeri harcamalarını ve doğrudan yabancı yatırımlarını dikkate alan Çevresel Kuznets Eğrisi modelini tahmin ederek literatürdeki boşluğu doldurmayı da amaçlamaktadır.

**Anahtar Sözcükler** : Çevresel Kuznets Eğrisi, BRICS, Askeri Harcamalar, Nükleer Enerji, Doğrudan Yabancı Yatırımlar.

## 1. Introduction

Achieving a stable level of economic growth is a fundamental objective shared by all nations. The Second World War severely damaged the economies of many countries. Countries started to develop aggressive growth policies to overcome the destruction caused by war. Since then, the amount of carbon emissions into the atmosphere has increased globally. This choice of countries brought the sustainability of natural resources, one of the basic inputs of economic activity, to the agenda.

The BRICS countries (Brazil, Russia, India, China, and South Africa), which are the focus of this study, are among the countries that produce significant carbon emissions worldwide. The carbon emission levels of these countries and their reasons can be analysed under several headings:

- **Industrialisation**: The BRICS countries undergo a faster industrialisation process than industrialised countries. As a major industrial production centre, China, in particular, uses large quantities of fossil fuels.
- **Energy Production**: Energy production in these countries is generally based on fossil fuels, including coal, oil, and natural gas. China and India have large shares of coal in electricity generation.
- **Population**: The BRICS countries comprise a significant portion of the world's population. The large and rapidly growing population increases energy demand, leading to higher carbon emissions.
- **Agriculture and Forestry**: Agricultural activities and deforestation are significant sources of carbon emissions, particularly in Brazil, where the destruction of Amazonian forests has had a considerable impact. Agricultural employment and natural resource utilisation often ignore environmental sustainability.
- **Economic Growth**: These countries are increasing industrial and energy production to sustain economic growth. This process is usually carried out without considering environmental impacts.
- **Political and Social Factors**: Factors such as government policies shaped within the framework of the geopolitical position, military expenditures, environmental regulations, renewable energy investments and increased environmental awareness may affect carbon emissions in BRICS countries.

Economic activities, such as significant increases in military expenditures and investments, can cause environmental problems. These ecological problems also disadvantage the economic structure. The economy and the environment have a mutually impacting relationship. Therefore, ecological resources are an important factor in sustainable economic development. Most countries also have a dynamic relationship between environmental sustainability, investments, and economic activities. Clean energy options are crucial for economic recovery and development in this context.

As is well known, energy is crucial for the continuity of economic activities (Bozkaya et al., 2022: 82600). Studies show that countries that produce nuclear energy tend to exhibit good economic performance and high levels of environmental sustainability (Apergis, 2016: 268). Continuous efforts are being made to promote a clean and sustainable environment worldwide. In many studies, the use of nuclear energy is becoming increasingly widespread due to its low carbon emissions (Duran et al., 2022: 70570). Governments also provide support for clean energy and the environment. It should not be forgotten that nuclear energy offers a way to achieve a resilient and low-carbon system. While countries make military expenditures and investments, they take various measures to reduce nuclear energy and carbon emissions. These measures have also become prerequisites for sustainable development, making it essential for the global economy to address the negative impacts of global warming. It is necessary to remember that renewable energy largely relies on natural cycles, and investments must be made to develop infrastructure that harnesses these cycles effectively. It is observed that most developing countries that prefer nuclear energy are unable to make these investments.

There is a lack of research in the literature on the relationship between military expenditures and the EKC. However, capitalism drives countries to engage in wars and acquire better and superior weapons (Elveren, 2021: 9), thereby increasing the importance of military expenditures for national economies daily. The political and economic systems implemented in recent years have led to increased tensions between countries. Events such as the Russia- Ukraine War and the tensions in the Middle East, such as the Israeli-Palestinian War, which have become almost commonplace, result in increased military expenditures. In today's world, systems are being destroyed by war on one hand and rebuilt on the other, revealing that the primary goal of countries in defence and security is to maintain stability. Thus, countries must choose to direct more of their capital to military expenditures. This study was conducted to address this gap and highlight the importance of the issue. The hypothesis obtained by Kuznets in his time series study, which utilised data sets from Germany, England, and the USA, has guided our study. The impact of economic activities and economic growth on the environment remains a subject of ongoing scientific study. The EKC expresses the relationship between national income per capita and environmental pollution. According to Kuznets (1955), a relationship exists between environmental pollution and economic development. This relationship is shaped like an "inverted U." The EKC explains the relationship between the deterioration of environmental conditions and the per capita income level. In his study, Kuznets revealed that environmental pollution initially increases and then decreases during the phase of economic growth and development (Akyıldız, 2008: 142-143). In other words, when economic growth increases, environmental pollution initially increases, the trend reverses after a particular threshold value, and as the level of economic development increases, environmental awareness increases and environmental pollution decreases (Erataş & Uysal, 2014: 6). The reason for the inverted U-shaped relationship between per capita income level and environmental pollution is due to structural and technological effects. In economies heavily reliant on agriculture, the environment is significantly impacted. However, with the development of industry and the use of clean and advanced tools, the rate of environmental pollution has decreased. In short, while increased industrialisation sometimes leads to environmental degradation, it also yields positive results in some countries. In other words, another essential point in the EKC is that as income levels continue to increase, the inverted U-shape situation reverses, and thus, environmental degradation decreases. Kuznets also emphasised the need to increase environmental awareness and stated that environmental pollution should be reduced.

The BRICS countries (Brazil, Russia, India, China, and South Africa) play a crucial role in analysing the EKC because these nations exhibit distinct dynamics in their economic growth processes and environmental issue management. Here are some points that highlight the significance of BRICS countries in the analysis of the EKC:

- **Stages of Development**: The BRICS countries represent various stages of development within the EKC. While some countries are undergoing rapid industrialisation, others are making progress in addressing environmental degradation.
- **Economic Growth:** With their high growth rates and large populations, the BRICS countries account for significant environmental changes and resource consumption. Understanding whether economic growth leads to environmental impacts is critical for analysing developments in these nations.
- **Policies and Governance:** The BRICS countries adopt different approaches to developing environmental policies and laws. This diversity can provide valuable insights for determining adequate ecological protection and sustainable strategies.
- **Global Impact:** The BRICS countries account for a significant portion of global carbon emissions. Therefore, understanding the relationship between environmental quality and economic growth in these nations and developing applicable policies is crucial for global environmental policies.
- **Interpretive Differences:** The BRICS countries may experience the EKC differently due to the influence of diverse cultural, political, and economic structures. This situation allows for universal lessons to be drawn for environmental management and sustainable development policies.

In summary, the BRICS countries provide the necessary depth and variety to understand the relationship between economic growth and environmental quality within the context of the EKC. Their experiences can also yield significant insights for other developing nations.

The study’s primary purpose is to investigate how the relationship between environmental quality and economic growth, known as the Environmental Kuznets Curve (EKC), changes in the context of nuclear energy use and military expenditures for developing economies. The policy problem this study focuses on is whether the defence expenditures of developing countries, due to the geopolitical risks they face and the cheaper nuclear energy they use to fuel their growing economies, support environmental degradation.

This is because if countries that have achieved a certain level of economic growth through defence expenditures and nuclear energy consumption cause an ecological disaster over time, it will destroy the importance of the economic success previously achieved for future generations. This study focuses on BRICS countries to investigate the relationship between environmental quality, military expenditures, and nuclear energy use. These countries, which have been the subject of many economic studies, attracted attention in 2001 when Jim O'Neill, an economist working at Goldman Sachs, coined the term 'BRIC', which consists of the initials of Brazil, Russia, India and China (O'Neill, 2001:1). At that time, these countries had large surface areas and middle-income but rapidly growing economies. For these reasons, they were projected to be among the world's largest economies by 2050. In 2006, these four countries officially came together to form BRIC. With South Africa's participation in 2010, this group was renamed BRICS. BRICS countries, which have achieved stable growth, are the most suitable country group for this study's empirical analysis, as they can produce nuclear energy and continually expand their military assets due to various geopolitical conflicts.

The study is organised into three sections. The first section will draw the conceptual framework of the EKC. The second section presents a literature review of studies on the EKC. In the third and final section, the relevant data of some countries that can produce nuclear energy will be subjected to econometric analysis, and the shape of the EKC in these countries will be determined. The study concludes with a section that evaluates the findings of the econometric analysis.

## 2. Conceptual Framework

The EKC explains the relationship between per capita income and environmental pollution. Its theory is based on the work of Simon Kuznets. In his study, Kuznets (1955) revealed the relationship between economic growth and income distribution. Accordingly, it is argued that income inequality will increase in the early stages of economic growth and decrease later.

This idea, put forward by Kuznets, became an important issue to be emphasised. Many transnational organisations have organised conferences on the subject to raise awareness. In the 1990s, factors such as the use of fossil fuels in energy supply and the greenhouse effect caused by gases released into the atmosphere brought the relationship between the environment and economic growth back to the top of the world agenda. Research on the relationship between economic growth and environmental pollution began to shift towards the Environmental Kuznets Curve (EKC) with the availability of data sets on many pollutants through the Global Environmental Monitoring Systems, established to monitor air quality in cities (Bo, 2011: 1322).

The concept of EKC was first used by Panayotou in 1993. Based on the relationship between per capita income and income inequality proposed by Kuznets in 1955, Panayotou argued for the existence of an inverted U-shaped relationship between environmental pollution and economic growth (Panayotou, 1993: 14). The reason why this name refers to the relationship between economic growth and environmental pollution is that it reveals an inverted “U” shaped relationship, with low levels of income tending to increase income inequality, while high levels of income tend to reduce it.

The EKC theory posits that environmental degradation caused by increased production in the early stages of economic growth will be mitigated and that this growth will ultimately improve the environment, particularly in the economies of developed countries (Stern, 1998: 173).

The early stages of growth in developing economies are primarily focused on producing industrial products that generate greenhouse gas emissions. In this stage, people’s disposable incomes are scarce. Similarly, businesses have almost no budget for measures to prevent environmental degradation. In the next stage of economic growth, the use of natural resources is expected to increase production volume again, and carbon emissions will also rise due to the waste generated by production. As the relevant country’s GDP per capita and welfare level increase, environmentally friendly policies may become more prominent on the agenda (Panayotou, 1993: 14).

Subsequent studies have tried to determine the curve's shape using different variables. While some suggest that the curve may be “N,” others have found it to be an inverted “U,” similar to the first version.

### 2.1. Determinants of the EKC

Many factors determine the process described by the EKC theory. These factors also address many economic phenomena in nature. The factors affecting the formation of EKC can be listed as follows (Grossman & Krueger, 1991: 3-4; Dinda, 2004: 435-436):

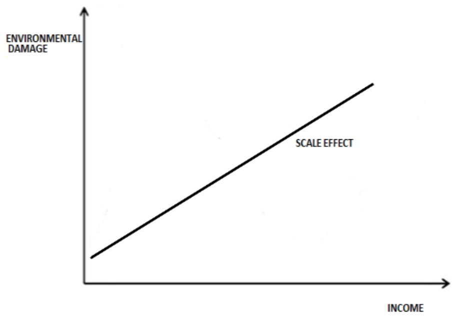
- Scale Effect
- Composition Effect
- Technological Effect

#### 2.1.1. Scale Effect

According to the scale effect, economic growth and environmental pollution exhibit a similar directional relationship. The technical impact of economic growth has limited ecological benefits. The composition effect of economic growth varies depending on the country’s comparative advantage (Ang, 2009: 2659). The increasing part in the first stage of the EKC refers to the scale effect, while the decreasing part refers to the composition and technical effect (Başar & Temurlenk, 2007: 2).

According to the EKC theory, after a sufficient level of economic growth is reached, further economic growth leads to environmental degradation. Primary production is more prioritised in the early stages of economic development. Therefore, economic activities are limited in scope. This results in a reduced amount of waste being produced. With the economic structure and industrialisation that emerge after primary production, excessive consumption of natural resources increases the amount of garbage. Therefore, at this stage, a same-directional relationship is observed between environmental degradation and income level (Kaika & Zervas, 2013: 1393).

**Figure: 1**
**Scale Effect**




*Source: Halkos, 2011: 9.*

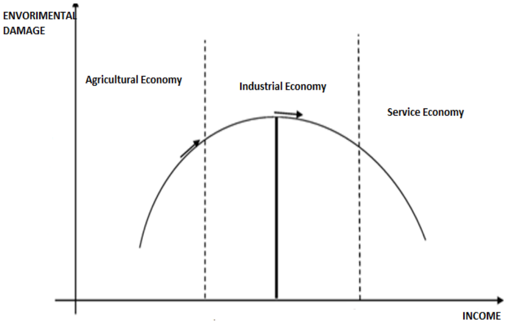
Figure 1 above shows the scale effect. At this stage of the EKC, environmental damage increases as income levels rise. The scale effect refers to the stage before the threshold point predicted by the theory.

### 2.1.2. Composition Effect

In contrast to the scale effect, the composition effect refers to the positive impact of economic growth on environmental degradation. The structural and fundamental changes made in the country under study exemplify this effect (Panayotou et al., 2000: 6). As is well known, a country's economic growth typically begins with the agricultural sector. Afterwards, economic growth is realised under the leadership of the industrial sector. However, this situation is different in countries where the capital factor is abundant. In these countries, economic growth shifts towards the service sector rather than the industrial sector. Along with the service sector, the information sector is also in a critical position (Başar & Temurlenk, 2007: 2). Since the inputs of these sectors are human-based resources such as ideas, human resources, etc., the resulting product does not cause any degradation on the environment (Panayotou et al., 2000: 6).

With the transition from agriculture to industry-based growth, migration from rural to urban areas is increasing. This can lead to environmental degradation. As a result of the increase in urbanisation, the rise in energy use causes ecological damage, and the increase in waste production also exacerbates environmental damage (Panayotou, 1993: 1). With the advancement of technology, continuous economic growth eventually increases the demand for services in the sector. This shift from the industrial sector to the service sector results in a decrease in the use of natural resources and environmental degradation. In this respect, the composition effect refers to the part of the EKC that reaches the threshold point and enters a downward trend (Dinda, 2004: 435-436).

**Figure: 2**
**Composition Effect**




*Source: Halkos, 2011: 9.*

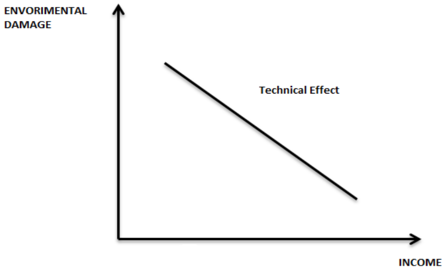
### 2.1.3. Technical Effect

Technical effect emerges at later stages of economic growth. Like the composition effect, it contributes positively to environmental degradation (Borghesi, 1999: 6-7). As economic growth, per capita income, and foreign trade increase, the demand for ecological improvement will also rise. The technical effect tries to prevent environmental degradation through environmentally friendly business models it creates (Cole & Elliott, 2003: 364). Increasing the level of R&D expenditure to generate innovation and understand efficient production can prevent environmental degradation. The fact that R&D expenditures adopt an environmentally friendly approach in production technology is vital to this (Ang, 2009: 2659).

Technical effect aims to create less input and less environmental pollution to achieve a specific output. In economies where per capita income exceeds a certain threshold, resources allocated to R&D expenditures and innovation studies are likely to yield new technological developments (Grossman & Krueger, 1991: 4). Environmental degradation is minimised through R&D expenditures and technological advancements (Karagöz-Domaç, 2022: 27).

As shown in Figure 3, in countries where the per capita income level has increased and reached a certain threshold, more can be achieved with fewer natural resources, thanks to R&D expenditures aimed at developing new technical innovations. This prevents environmental degradation.

**Figure: 3**
**Technical Effect**




*Source: Halkos, 2011: 9.*

### 2.2. Different Views of EKC

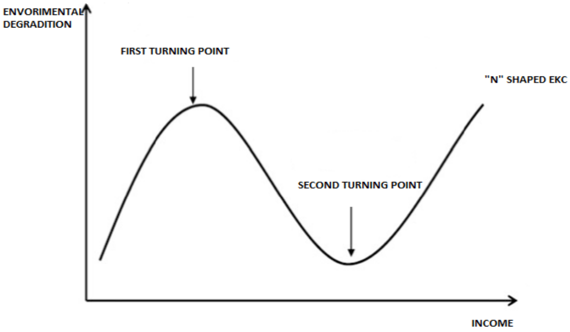
Studies on the EKC hypothesis mainly focus on the curve's inverted "U" shape. On the other hand, other studies have also included different views of the curve (De Bruyn et al., 1998: 162). Thus, the new EKC theories that have emerged are referred to as N-shaped and M-shaped. The EKC hypothesis's N- and M-shaped tests indicate that more than one threshold point may occur in the long run. Unlike these two approaches, there is also a different version in the literature where the hypothesis is tested and the "race to the bottom theory" (Rasli et al., 2018: 3121).

#### 2.2.1. "N" Shaped EKC

The addition of the mathematical third power of the national income per capita to the tests of the EKC hypothesis reveals that the relationship between environmental pollution and income may differ in the long term. This differentiation suggests that after a certain income level, environmental pollution may increase due to increased stimulation. The focus of this version, known as the "N"-shaped EKC theory, is that the scale effect outweighs the composition and technical effects by magnitude (Torras & Boyce, 1998: 157). Sources of this new situation include the lack of opportunities to increase the distribution of industries that improve environmental quality and decreasing returns experienced in technological changes. For the aforementioned reasons, instead of the EKC hypothesis with a single threshold point, which predicts an inverted U-shaped change, an N-shaped relationship with two threshold points emerges, and environmental pollution increases again in the long term (Allard et al., 2018: 5849).

Figure 4 illustrates the N-shaped Environmental Kuznets Curve (EKC). Accordingly, in addition to the inverted U-shape, it is assessed that a second threshold point will occur as national income per capita increases. Unlike the first one, this new threshold point suggests that environmental degradation will start to increase again. In this respect, a second threshold point is not a harbinger of good things for the environment.

**Figure: 4**
**“N” Shaped EKC**




*Source: Balsalobre et al., 2017: 258.*

### 2.2.2. “M” Shaped EKC

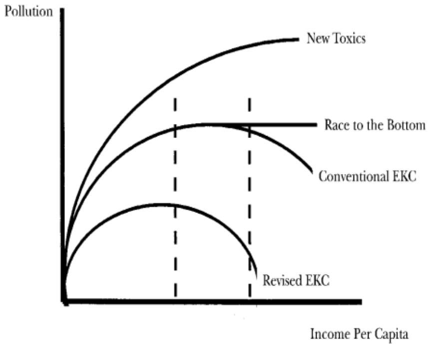
In studies on the EKC theory, the M-shaped EKC was obtained by adding a fourth power to the mathematical power of three of national income per capita (Terrell, 2021: 164). The M-shaped and N-shaped EKC theories examine whether a third threshold point exists in the long term. It would not be wrong to say that the technological development expected to reduce environmental degradation is disrupted, and sectors are transformed with a third threshold point. It is also considered that fairness in income distribution and political instability may pave the way for a third threshold point. In addition to the mentioned factors, the M-shaped EKC hypothesis may also arise due to increasing agricultural production per acre and urbanisation (Terrell, 2021: 158-161).

### 2.2.3. Race Towards the Bottom EKC

Many economists have criticised the traditional EKC theory. Some economists have argued that the curve will shift from its current pollution level to a maximum straight line over time and that foreign trade and foreign investments will pressure environmental quality, leading to adverse environmental effects. The literature describes this situation as a race to the bottom (Dasgupta et al., 2002: 148).

Good environmental regulation standards impose significant costs on pollution producers. The opportunity to invest in foreign countries, which increases with globalisation, may lead to avoiding the costs of environmental regulations in high-income countries. As a result, investments in low-income countries with flexible environmental standards increase. Due to the increased capital outflows from high-income countries, these countries attempt to prevent capital outflows by making environmental standards more flexible. Flexible environmental standards can lead to a race to the bottom among countries as economic activities gradually increase environmental pollution (Wheeler, 2001: 226).

**Figure: 5**
**Race to the Bottom EKC**




*Source: Dasgupta et al., 2002: 148.*

In Figure 5 above, four curves reflect the relationship between pollution and per capita income level. The top curve indicates that even as some pollution indicators decrease with increasing income levels, environmental pollution will continue to rise with the emergence of new toxins. The second curve, known as the race to the bottom, indicates that countries prioritise production over environmental values with globalisation, and environmental degradation tends not to decrease (Dasgupta et al., 2002: 148). The revised EKC at the bottom shows that the traditional level of EKC has declined and shifted to the left, as the pollution level has started to decrease at lower income levels (Pata, 2019: 70).

## 3. Literature Review

In today’s world, societies are increasingly concerned about environmental issues, climate change, resource scarcity, and pollution, which are becoming significant challenges for people and major environmental problems in both the public and private sectors. The EKC is one of the most widely used theories to explain the relationship between economic growth and environmental conditions. It is emphasised that the environmental quality caused by increasing economic activities in developing countries should be improved at the maximum level. This literature review aims to compile studies that examine the relationship between the Environmental Kuznets Curve (EKC) Hypothesis and military expenditures, as well as nuclear energy use.

Wang et al. (2024) examine the environmental impact modelling and efficient use of renewable and nuclear energy by taking into account the effects of energy efficiency within the framework of the EKC and LCC hypotheses in BRICS countries from 1990 to 2018. Long-term forecasts are based on LM-Bootstrap Cointegration tests and Drisscoll-Kraay regressions. In this study, it is observed that financial development has a negative relationship with the load capacity factor, while it has a positive relationship with CO2 emissions. These findings suggest the EKC and LCC hypothesis in BRICS countries.

Jaeger et al. (2023) reassess the EKC hypothesis, where pollution rises gradually and then takes an inverted U-shape with increasing income. This study supports this literature in two main ways. These are theoretical and empirical data. When the theoretical assumptions about changing populations are integrated with the empirical model formulation, the results show an inverted U-shaped relationship between increasing income and population density and emissions causing air pollution. These results offer an additional perspective on the EKC literature and the expectations and claims regarding the potential decoupling of economic growth from environmental damage.

Raihan (2023) examined the impact of FDI on the EKC in Bangladesh and confirmed its adverse effects on the environment, supporting the Pollution Haven Hypothesis (Raihan, 2023).

Using a panel dataset from 1990 to 2020, Baba (2023) tests the EKC with mean group (MG) and pooled mean group (PMG) estimation results to examine the long-term and short-term effects of renewable and non-renewable energy, economic growth (GDP) and carbon dioxide (CO2) emissions in 16 developing countries. The empirical results support the EKC hypothesis by providing evidence of a positive relationship between environmental degradation and economic development in the short and long run when environmental degradation is chosen as the dependent variable. The study concludes that the EKC suggests policymakers should consider reducing environmental degradation in both the short and long term, and use appropriately coordinated economic policies when making policy recommendations.

The impact of FDI on environmental pollution was also examined by Wu & Wang (2023), who found an Inverted U-shaped relationship in China, indicating the potential impact of FDI on regional air pollution, in line with the EKC hypothesis (Wu & Wang, 2023).

Józwik et al. (2023) aim to measure the validity of the N-shaped Environmental Kuznets Curve (EKC) hypothesis while reevaluating the impact of nuclear energy use and financial development on the environment within the framework of annual data available from 1993 to 2019, focusing on the 11 countries with the highest atomic energy consumption. The findings suggest a long-term cointegration relationship between the variables. According to the results of the PCSE model, in the first 11 countries, an increase in nuclear energy consumption is associated with a decrease in carbon emissions. Based on the results obtained and the literature analysis, it is emphasised that investments and subsidies for R&D studies should be increased within the framework of identifying and implementing innovative solutions to reduce carbon emissions and improve environmental quality.

Golpîra et al. (2023) investigate the validity of the EKC hypothesis for countries belonging to the Organization for Economic Cooperation and Development (OECD), which includes 37 countries, between 1960 and 2019. Panel Quantile Regressions (QR) are used in these investigations. The findings indicate that cointegrated regressions reveal that economic growth, fossil fuel consumption, and population negatively impact the environment, while renewable energy consumption reduces carbon dioxide (CO2) emissions. Panel causality tests confirm these results, suggesting a feedback mechanism between CO2 emissions and the rest of the series.

A study by Sattar et al. (2022) has examined the relationship between military expenditures, foreign direct investment (FDI), and the EKC. Analysing the effects of China's FDI on environmental pollution in South Asian countries, Sattar et al. (2022) provided insights into the impact of FDI on environmental degradation. They provided a perspective on the environmental impact of FDI.

Cutcu et al. (2024) investigate the interaction of foreign trade and military spending with ecological concerns in the US economy using available time series techniques. The analysis utilizes annual data for the US economy between 1970 and 2018, incorporating variables such as military expenditures, ecological footprint, imports, and exports. In the methodology applied, it is explained that a long-term relationship exists between the variables, as indicated by the cointegration test results. This study aims to investigate the relationship between military expenditures and environmental degradation and to examine the role of economic progress in this process. The analysis employs various methods, including fixed effects estimation, Driscoll-Kraay, Lewbel (2SLS), Oster, structural VARs, and quantiles. The results show that military spending has a significant and positive impact on environmental indicators, including nitrous oxide, methane, and carbon dioxide. This suggests that although African countries do not produce weapons, their military spending still contributes to environmental degradation. Therefore, regulating military expenditures in the continent is of critical importance.

Ahmed et al. (2022) investigated the effects of defence expenditures on the environment for 22 OECD countries using data from 1971-2020. According to the results, defence expenditures increase carbon dioxide emissions.

Pirgaip et al. (2023) assess the role of government spending in environmental sustainability based on a framework that combines the EKC hypothesis with the Armey Curve hypothesis. The inverted U-shaped relationships between carbon (CO2) emissions and economic growth (EKC hypothesis) and between government spending and economic growth (Armey curve hypothesis) are analysed using a composite EKC model that is tested for cross-sectional dependence and heterogeneity, panel unit root, panel cointegration and augmented mean group estimation. The empirical results confirm that economic growth serves as a mediator between government spending and CO2 emissions in the US, UK, and Canadian governments.

As a result, the relationship between the EKC Hypothesis, military expenditures, and nuclear energy use is an inverted U-shape. Increased nuclear energy use reduces CO2 emissions and positively impacts environmental improvement, while a positive short- and long-term relationship exists between economic development and environmental degradation.

This literature shows that governments have a critical role to play, according to the results obtained in the relevant studies. It also emphasises that governments can achieve better results if their economic policies are more sustainable and properly coordinated in both the short and long term to minimise environmental degradation.

Cole (2004) investigates the extent to which the EKC inverted U relationship can be interpreted in terms of trade, specifically the relocation or displacement of ‘dirty’ industries from developed to developing regions, known as the pollution haven hypothesis (PHH). Evidence for the PHH is assessed based on detailed data on north-south trade flows for highly polluting products. Emissions of 10 air and water pollutants are then estimated considering trade openness, structural change and dirty North-South trade flows. Evidence of pollution haven effects is obtained, but such effects are infrequent and relatively small compared to other explanatory parameters. This paper examines the arguments for the pollution haven hypothesis and assesses how trade contributes to the EKC relationship through pollution haven effects and structural change.

Dietz and Rosa (1994) discuss the need to better understand the linkages between population, resources, and environmental impacts, to continue developing structured research programs to investigate these linkages and to test conceptual models empirically, with a focus on anthropogenic environmental changes. The IPAT model is proposed to illustrate these issues, as it is considered an appropriate way to meet the requirements of statistical measurement. A brief historical account of the scientific discourse on the problems is described. It is noted that the social sciences, on the one hand, and the biological and environmental sciences, on the other, have addressed these issues in parallel but often separately and in opposition. It then describes the original IPAT model and the proposed modifications, assessing the strengths and weaknesses. Modifications, details, and instructions for further testing of the model are described, along with some recommendations for replacing the IPAT model.

Ehrlich and Holdren (1971) emphasise that as the intertwined crises of population, environment and resources have become the focus of numerous studies, articles and an ever-increasing number of publications, many claims have been made, the most important of which is the misunderstanding of facts such as the idea that the proportion of the US population, its growth rate, is a marginal contributor to the negative impact of the US on the local and global environment and that the issue should be revisited in this article because it has not gained a serious place in the literature. The discussion is structured around five theorems believed to have been proved and provides a setting for realist analysis. According to the findings obtained within the framework of the theorems, the problems faced by humanity are defined as “a storm of crisis problems”, and it is emphasised that it is not enough to offer uniform solutions to these problems. It is argued that multifaceted strategies, such as population control, reorientation of technology, and equality of opportunity, are necessary for the future. Ignoring the environmental impacts of population growth is dangerous, and this problem must be addressed.

Grossman and Krueger (1991) provide empirical evidence to assess the relative magnitude of these three effects of increased trade liberalisation in Mexico, as a reduction in trade barriers affects the environment by opening up economic activity, changing the patterns of economic activity, and creating a difference in production techniques. It utilises comparable measurements of three air pollutants in a sample of urban areas across 42 countries to examine the relationship between economic growth and air quality. It examines how pollution abatement costs in the US industry, which are significantly higher than those in other countries, affect international trade and investment patterns. We also use the results of a computable general equilibrium model to examine the impact of NAFTA on pollution in Mexico. The findings suggest that some aspects that could have been particularly beneficial for Mexico may have been overlooked. Interest in the US market, combined with a more liberalised trade regime, provides a potential revenue boost for Mexico. However, it also suggests that trade liberalisation could increase Mexican specialisation in sectors with a lower-than-average impact on environmental damage.

Holdren (2021) states that the IPAT equation, developed by Paul Ehrlich and John Holdren in 1972, explains that environmental impact (I) is a function of population (P), affluence (A), and technology (T). The equation is expressed as ($I = P \times A \times T$). As late as 1969, Holdren and Ehrlich, in their refutation of Commoner’s claim that increasing material consumption with population growth is not a cause for concern, emphasised that all variables are important, that they interact, and that it is dangerous not to consider any of the relevant variables or their interactions. As a result, the critique explains that factors are interconnected and that the environmental consequences of population growth are considerable, thereby demonstrating that Commoner’s arguments are flawed in logic and arithmetic.

Kornecki and Wise (2024) describe the opportunities and barriers to implementing advanced nuclear reactors and nuclear reactor-related fuel cycles, as described in the Two National Academies consensus report. It describes consensus propositions that these new technologies can achieve commercial success as part of a long-term decarbonisation strategy. It highlights that decarbonizing the economy to mitigate climate change presents a significant opportunity for advanced nuclear reactors, but that many challenges need to be overcome before they can benefit the low-carbon energy system in the future. Considerable effort and financial support from several institutions are required to overcome these challenges.

In this paper, Kuznets (1955) discusses the nature and causes of long-term changes in personal income distribution, examining whether inequalities in income distribution will increase or decrease with a country’s economic growth and what factors will determine this outcome. Although the reliable information and empirical results presented in the article are considered to be insufficient, it is emphasised that accepting the subject as a heuristic method that requires further research rather than purely empirical results will both provide an opportunity for the subject to be chosen as a subject of further research and shed light on future studies and research on the subject.

Panayotou (1993) empirically tests the hypothesis of an inverted U-shaped relationship between environmental degradation and economic development, emphasising policy implications for technology transfer, employment and development assistance. Using data on air pollution and deforestation from developed and developing countries, the findings support the hypothesis that the inverted U-shaped EKC called the EKC, resembles the inverted U-shaped relationship between development and inequality. He argues that part of the sharpness of the inverted U-shaped relationship between environmental degradation and growth is due to policy distortions, such as energy and agrochemical subsidies, industrial protection and undervaluation of natural resources, which have dire economic and environmental consequences, while another part is due to market failures, such as ill-defined property rights over natural resources and unaccounted and unpaid environmental externalities that lead to unnecessarily high levels of resource consumption and pollution per additional unit of output.

Pearce (2012) describes the research and analysis of the challenges that nuclear energy must overcome to be sustainable. The results indicate that nuclear energy cannot be considered a sustainable source. It is emphasised that it is not enough to develop innovative solutions to reduce the environmental burdens of atomic energy technology; the nuclear industry must also address fair sustainability issues for current and future generations. The study concludes that a sustainable nuclear energy system must achieve radical improvements in greenhouse gas emission intensity through improved technology and efficiency to replace fossil fuels, minimise the risks associated with nuclear power and eliminate nuclear mistrust, minimise the environmental impacts of radioactive waste disposal and mining activities, and restore public confidence in the nuclear industry through rapid improvements in the performance of renewable energy technologies.

Torras and Boyce (1998) apply the concept of ‘political and social economy’ to Kuznets’ (1955) hypothesis on the relationship between per capita income and environmental pollution. They argue citizens’ demands are important in promoting pollution-reducing policies and technological change. To do so, they emphasise Boyce’s (1994) view that equitable power distributions are highly likely to result in better environmental quality, among other things.

Eylasov et al. (2024) investigate the impact of military expenditures and financial development on economic growth using data for BRICS+T countries (Brazil, Russia, India, China, South Africa and Türkiye) for the years 1992-2021 within the framework of the Benoit hypothesis. The stationarity of the variables is observed using ADF and Flexible Fourier ADF unit root tests. Then, the cointegration relationship between the variables is examined using Fourier Bootstrap ARDL and Bayer-Hanck methods. In Türkiye, only the FB-ARDL method finds a cointegration relationship. At the same time, according to the FB-

ARDL long-run estimation results, financial development has a positive effect on economic growth in Türkiye, while military expenditures have a negative effect. FMOLS long-run estimation results for BRICS countries show that the impact of financial development on economic growth is positive and significant in all countries except Brazil and South Africa. At the same time, military expenditures have no statistically significant effect on economic growth in Russia and China. In Brazil, India and South Africa, military expenditures have a negative impact on economic growth. In the study, the causality relationship between the criteria for all countries is analysed using the Fourier Toda-Yamamoto method and new policy recommendations are presented within the scope of the results.

(2024) integrate technological innovation, militarisation and environmental change into an integrated analytical framework to assess the potential impact of technological progress and military defense spending on the environment in BRICS countries. Based on CSD, unit root, and cointegration tests, they construct a CS-ARDL model to observe the long- and short-term relationships between different factors from 1990 to 2021. The results show that technological innovation, military spending and economic growth significantly increase the ecological footprint in the long run, while technological innovation and economic growth increase the ecological footprint in the short run, but military spending does not have a significant impact. It is recommended that BRICS countries focus on promoting low-carbon technology policies and R&D investments and using advanced technologies to improve military intelligence capabilities to minimise the negative impact of technological innovation and military activities on the environment.

Thomas et al. (2023) examine the relationship between military expenditures and income inequality in BRICS countries. Different sources such as the World Bank's World Development Indicators and Penn World Tables are utilised while using panel data. To explain the impact of military expenditures on income inequality, a pooled mean group (PMG) or panel autoregressive distributed lag (PARDL) approach is used for 1990-2017 in BRICS countries. The empirical result for the pooled sample reveals an inverse relationship between military expenditure and income inequality, whereas a percentage change in military spending leads to a reduction in the income inequality problem for the BRICS countries. The results of the empirical study suggest that policymakers should focus more on developing economic activities in the BRICS countries and on policies to minimise income inequality.

In addition, Hacıimamoğlu (2022) suggested in his study that the Environmental Pollution Haven Hypothesis has a positive relationship between environmental pollution and FDI and concluded that this relationship is valid for BRICS-T countries, pointing out the potential impact of FDI on environmental degradation (Hacıimamoğlu, 2022 ).

Erdogan et al. (2022) investigated the relationship between defense expenditures and environmental quality for Greece, France, Italy, and Spain from 1965 to 2019 and concluded that there was an interaction in these countries. The interaction arises from national military expenditures and the defense expenditures of other regional countries.

Elgin et al. (2022) investigated the relationship between defense expenditures and sustainable development indicators of 160 countries from 1950 to 2018. They concluded that there was a positive relationship between military spending and air pollution.

Üzar (2019) examined the relationship between foreign direct investment inflows and carbon dioxide emissions, an environmental indicator, in Türkiye between 1970 and 2014, using the "race to the bottom" methodology. He showed that the EKC hypothesis validates the relationship between foreign direct investment and the environment.

Huang et al. (2019) and Abdulsalam et al. (2021) examined the effects of FDI on carbon emissions and provided valuable insights into its potential impact on environmental degradation. They highlighted the non-linear relationship between GDP growth and emissions and the critical role of FDI in economic growth (Huang et al., 2019; Abdulsalam et al., 2021).

Noubissi Domguia and Poumie (2019) investigated the impact of 54 countries' military expenditures on carbon dioxide, NO2, and CH4 from 1980 to 2016 and concluded that defense expenditures positively affect environmental indicators.

Zhang & Guo (2017) empirically tested the factors affecting the ecological footprint and revealed the existence of the EKC and the positive impact of FDI on ecological footprint, emphasising the potential impact of FDI on environmental sustainability (Zhang & Guo, 2017).

Neila (2016) investigated the relationship between defense expenditures and environmental pollution in 121 countries from 1980 to 2011. The results show that defense expenditures have a positive effect on carbon emissions.

Apergis (2016) also discussed the relationship between economic growth and environmental pollution under the EKC hypothesis. They provided insights to further understand the relationship between economic growth and environmental degradation by emphasising the extensive international literature focusing on environmental pollutants and the relationship between output and carbon emissions (Apergis, 2016).

## 4. Econometric Analysis

### 4.1. Empirical Model and Data

The empirical studies examining the effects of various economic indicators on environmental impact factors can be said to have originated with the works of Ehrlich and Holdren (1971) and Holdren and Ehrlich (1972). In these studies, the authors proposed a new model abbreviated as IPAT. This abbreviation stands for environmental impact (I), population (P), affluence (A), and technology (T) and is expressed as follows (Holdren, 2021):

$$I = PAT \tag{1}$$

In equation (1), I represents environmental impact, which can be considered the total footprint of human activities on nature. P indicates the size of the population. A represents affluence per capita, typically measured by income or consumption levels per person. Finally, T represents the effects of technologies used in production processes and human life on the environment. The IPAT model is used as a tool in studies related to environmental sustainability and development policies. The model offers a valuable and straightforward roadmap for understanding the environmental impacts of population, affluence, and technology variables and for developing environmental policies. However, since this model addresses environmental impacts only through a multiplicative relationship, it cannot fully explain complex interactions. At this point, the literature introduced the Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) model, developed by Dietz and Rosa (1994). This model was initially proposed to evaluate the effects of population, affluence, and technology on environmental impacts in a more flexible and complex manner. The study by Dietz and Rosa (1994) expanded upon the critiques of the IPAT model, providing a more advanced framework for analysing environmental impacts. The STIRPAT model can be expressed as follows:

$$I = \alpha P^{\beta} A^{\gamma} T^{\delta} \tag{2}$$

Unlike the equality in (1), the parameters $\alpha$, $\beta$, $\gamma$ and $\delta$ here are elasticity parameters that reflect the impact of population, wealth, and technology on environmental impact factors. While IPAT-type models continue to be developed, another model aiming to explain the relationship between environmental impact and economic indicators has begun to be discussed in the literature. The empirical model proposed by Kuznets (1955), which aimed to explain the relationship between income inequality and economic growth, has evolved into a model that seeks to explain the relationship between economic growth and environmental degradation by substituting the dependent variable with any environmental impact factors. The first study to achieve this transformation without referencing Kuznets by name and to apply it was Grossman and Krueger (1991). However, the study that transformed Kuznets’ (1955) model to measure environmental degradation and named this new model the EKC was conducted by Panayotou (1993). The core of the EKC hypothesis model is as follows:

$$I = aY^{b}(Y^{2})^{c} \tag{3}$$

This mathematical expression assumes an inverted U-shaped relationship between the environmental impact factor (I) and growth or income (Y). In such a non-linear relationship pattern, the level of growth at the peak of the inverted U-shape gives the level of economic growth at which environmental degradation peaks in that country. This information is very important for policymakers. Knowing up to which level of growth the environment will be badly affected allows for robust policymaking. The EKC model differs positively from IPAT models with this extra information. This study uses the EKC model instead of the IPAT model since this specific growth level is to be estimated. After a two-sided logarithm transformation, the EKC model is transformed into one suitable for econometric analysis. After this transformation, various control variables can be added to the basic variables of the model by the literature. For example, Panayotu (1993) extended the model with a population variable and a dummy variable representing tropical countries. Torras and Boyce (1998) included the GINI coefficient, literacy rate and political rights - civil liberties index as control variables in the estimated model. In Cole (2004), the share of the manufacturing industry in GDP, trade intensity and exports and imports of dirty industrial products are included in the EKC model. As seen from the prominent studies in the literature, the EKC model can be extended with economic and/or social variables that are thought to impact environmental degradation. In this study, defense expenditures, foreign direct investments and nuclear energy use variables are used as control variables in the EKC model for the research in the models created for the BRICS countries that can produce nuclear energy. In addition, the population variable, which has an important place in IPAT models, was also included as a control variable in one of the models to be analysed in this study. Accordingly, the environmental Kuznets models used in the study are as follows:

$$lnce_{it} = \beta_{11} lny_{it} + \beta_{12} lny_{it}^2 + \mu_i + \eta_t + \varepsilon_{it} \tag{4}$$

$$lnce_{it} = \beta_{21} lny_{it} + \beta_{22} lny_{it}^2 + \alpha_2 ne_{it} + \mu_i + \eta_t + \varepsilon_{it} \tag{5}$$

$$lnce_{it} = \beta_{31} lny_{it} + \beta_{32} lny_{it}^2 + \alpha_3 me_{it} + \mu_i + \eta_t + \varepsilon_{it} \tag{6}$$

$$lnce_{it} = \beta_{41} lny_{it} + \beta_{42} lny_{it}^2 + \alpha_4 fdi_{it} + \mu_i + \eta_t + \varepsilon_{it} \tag{7}$$

$$lnce_{it} = \beta_{51} lny_{it} + \beta_{52} lny_{it}^2 + \alpha_5 p_{it} + \mu_i + \eta_t + \varepsilon_{it} \tag{8}$$

**Table: 1**
**Variables Used in the Empirical Analysis**

| Variable | Description | Data Source |
|---|---|---|
| $lnce_{it}$ | Carbon emissions (Tons per capita, natural logarithm) | World Bank World Development Indicators (WDI) |
| $lny_{it}$ | Gross Domestic Product per capita (2015=100, natural logarithm) | |
| $me_{it}$ | Military expenditures (% share in GDP) | |
| $fdi_{it}$ | Foreign direct investment (% share in GDP) | |
| $lnp_{it}$ | Population, natural logarithm | |
| $ne_{it}$ | Share of Nuclear energy in total energy consumption (%) | U.S. Energy Information Administration Database |

### 4.2. Empirical Analysis

A series of econometric tests need to be applied to estimate the parameters of the models defined by Equations (1)-(4). Since the data is panel data, cross-sectional dependence should be tested first. Cross-sectional dependence, like the unit root, is a vital panel data feature that, if present, will change the analysis path to be followed in revealing the economic relationships of interest. Therefore, the existence of this effect should be tested statistically first. Table 2 presents the results of the Pesaran (2004) test, which was performed on the panel data used in this study.

**Table: 2**
**Cross-Section Dependency Test**

| | $lnce_{it}$ | $lny_{it}$ | $ne_{it}$ | $me_{it}$ | $fdi_{it}$ | $lnp_{it}$ |
|---|---|---|---|---|---|---|
| CD Statistics | 8.823 | 16.005 | 5.241 | 3.680 | 1.703 | 5.39 |
| p-value | 0.000*** | 0.000*** | 0.000*** | 0.000*** | 0.089* | 0.000*** |

****, **, and * indicates statistical significance at 99%, 95%, and 90% confidence leves, respectively.*

The results in Table 2 reveal that the null hypothesis of the Pesaran (2004) CD test, which asserts that there is no cross-section dependence at the accepted levels of significance (5% and 1%), can be rejected for all variables except $fdi_{it}$. For $fdi_{it}$, the relevant null hypothesis can also be rejected at a 10% significance level. Therefore, it can be said that there is empirical evidence for the existence of cross-sectional dependence for all variables in the panel data. In this case, it is essential to use methods that consider cross-section dependence in the ongoing analyses. In this context, Pesaran's (2007) CADF unit root test, which is robust to cross-sectional dependence, is used for the unit root tests of the variables. The results are summarised in Table 3.

**Table: 3**
**Panel Unit Root Test Results**

| | $lnce_{it}$ | $lny_{it}$ | $ne_{it}$ | $me_{it}$ | $fdi_{it}$ | $lnp_{it}$ |
|---|---|---|---|---|---|---|
| Pesaran CIPS Test Statistics | -2.607<br>[0] | -2.786<br>[1] | -2.527<br>[4] | -3.135<br>[0] | -2.766<br>[0] | -3.783<br>[0] |
| p-value | 0.025** | 0.009*** | 0.039** | 0.001*** | 0.010*** | 0.000*** |

*The values in square brackets are the appropriate lag values selected according to the Akaike information criterion.*
****, **, and * indicates statistical significance at 99%, 95%, and 90% confidence leves, respectively.*

According to the unit root test results summarised in Table 3, $lnce_{it}$ and $ne_{it}$ are stationary at a 5% significance level. The other variables are stationary at a 1% significance level and lower. Since all panel time series compiled for the analysed countries are stationary, the causality tests can be applied directly, and the parameter estimates of the models expressed in Equations (4), (5), (6), (7) and (8) can be estimated with robust methods for cross-sectional dependence. In addition to these methods, the test results of Dumitrescu and Hurlin (2012), which are also robust test statistics for Granger causality between economic variables, are summarised in Table 4.

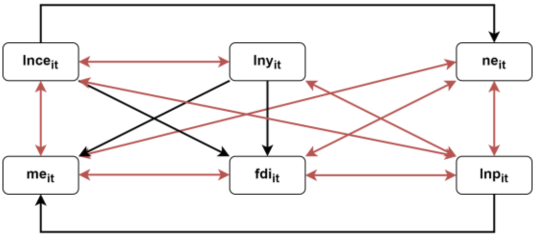
**Table: 4**
**Dumitrescu & Hurlin (2012) Granger Causality Test Results**

| Null Hypothesis | Lag | Test Statistics | p-Value |
|---|---|---|---|
| $lnce_{it}$ is not the Granger cause of $lny_{it}$ | 2 | 4.4068 | 0.0000*** |
| $lny_{it}$ is not the Granger cause of $lnce_{it}$ | 7 | 2.1643 | 0.0304** |
| $lnce_{it}$ is not the Granger cause of $ne_{it}$ | 7 | 2.8430 | 0.0045*** |
| $ne_{it}$ is not the Granger cause of $lnce_{it}$ | 1 | 1.3221 | 0.1861 |
| $lnce_{it}$ is not the Granger cause of $me_{it}$ | 7 | 2.8430 | 0.0045*** |
| $me_{it}$ is not the Granger cause of $lnce_{it}$ | 7 | 4.2012 | 0.0000*** |
| $lnce_{it}$ is not the Granger cause of $fdi_{it}$ | 7 | 5.0884 | 0.0000*** |
| $fdi_{it}$ is not the Granger cause of $lnce_{it}$ | 2 | -0.0066 | 0.9947 |
| $lnce_{it}$ is not the Granger cause of $lnp_{it}$ | 7 | 5.8255 | 0.0000*** |
| $lnp_{it}$ is not the Granger cause of $lnce_{it}$ | 7 | 10.3997 | 0.0000*** |
| $lny_{it}$ is not the Granger cause of $ne_{it}$ | 2 | 1.5919 | 0.1114 |
| $ne_{it}$ is not the Granger cause of $lny_{it}$ | 5 | 0.4654 | 0.6417 |
| $lny_{it}$ is not the Granger cause of $me_{it}$ | 2 | 4.8265 | 0.0000*** |
| $me_{it}$ is not the Granger cause of $lny_{it}$ | 2 | 1.1186 | 0.2633 |
| $lny_{it}$ is not the Granger cause of $fdi_{it}$ | 7 | 2.8597 | 0.0000*** |
| $fdi_{it}$ is not the Granger cause of $lny_{it}$ | 2 | -0.9861 | 0.3241 |
| $lny_{it}$ is not the Granger cause of $lnp_{it}$ | 7 | 12.1432 | 0.0000*** |
| $lnp_{it}$ is not the Granger cause of $lny_{it}$ | 7 | 13.5308 | 0.0000*** |
| $ne_{it}$ is not the Granger cause of $me_{it}$ | 7 | 4.2090 | 0.0000*** |
| $me_{it}$ is not the Granger cause of $ne_{it}$ | 7 | 7.1254 | 0.0000*** |
| $ne_{it}$ is not the Granger cause of $fdi_{it}$ | 1 | 3.0531 | 0.0023*** |
| $fdi_{it}$ is not the Granger cause of $ne_{it}$ | 3 | 2.0075 | 0.0447** |
| $ne_{it}$ is not the Granger cause of $lnp_{it}$ | 7 | 4.6201 | 0.0000*** |
| $lnp_{it}$ is not the Granger cause of $ne_{it}$ | 7 | 8.9757 | 0.0000*** |
| $me_{it}$ is not the Granger cause of $fdi_{it}$ | 1 | 13.0964 | 0.0000*** |
| $fdi_{it}$ is not the Granger cause of $me_{it}$ | 7 | 2.0428 | 0.0411** |
| $me_{it}$ is not the Granger cause of $lnp_{it}$ | 7 | -0.3984 | 0.6903 |
| $lnp_{it}$ is not the Granger cause of $me_{it}$ | 7 | 4.7092 | 0.0000*** |
| $lnp_{it}$ is not the Granger cause of $fdi_{it}$ | 7 | 6.1144 | 0.0000*** |
| $fdi_{it}$ is not the Granger cause of $lnp_{it}$ | 7 | 3.4789 | 0.0005*** |

****, **, and * indicates statistical significance at 99%, 95%, and 90% confidence leves, respectively.*

The causality diagram summarising the results in Table 4 can be formed as in Figure 6.

**Figure: 6**
**Granger Causality Relationships between Variables**




*Note: The red line indicates bidirectional causality relationships.*

The causality analysis findings provided important evidence about the existence of the economic relationships sought to be investigated and modelled using Equations (4), (5), (6), (7), and (8). Since all the variables in the panel data have cross-sectional dependence, the cross-sectional dependence-robust Common Correlated Effects Mean Group (CCEMG) and Common Correlated Effects Pooled Mean Group (CCEPMG) estimators recommended by Pesaran (2006) could be used in the parameter estimation process. With this strategy, the Kuznets curve parameters, shaped by nuclear energy demand, military expenditures, foreign direct investment, and population, are estimated for five developing countries that can produce nuclear energy.

### 4.3. Findings

Two primary empirical analyses are conducted in this study. Firstly, as in all panel data econometrics applications, cross-section dependence and second-generation unit root tests are performed. According to the findings, it is concluded that all variables in the panel data exhibit cross-section dependence, and the series is stationary. Based on these findings, Dumitrescu and Hurlin (2012) employed the Granger causality test, which revealed significant causal relationships between the variables. Accordingly, when focusing on the carbon emission variable for the five countries analysed within the framework of the EKC hypothesis, it is revealed that income and military expenditure variables are the Granger cause of carbon emission per capita. This empirical analysis could also detect the income-environmental impact relationship emphasised in the EKC hypothesis. In addition, defence expenditures, a component of public spending, significantly affect the forecast accuracy of per capita carbon emissions (as defined by the Granger Causality), which is considered an environmental impact factor in this study. It should also be noted that there is a bidirectional causality relationship between carbon emissions, income, and military expenditures. The five countries examined for nuclear power are located in regions at risk of serious conflict or adjacent to such regions. This includes areas with ongoing international conflicts, such as the Russia-Ukraine war. These geopolitical tensions have significantly influenced their military expenditures, potentially creating a reciprocal causality between military spending and the surrounding environment. Another conclusion from the causality analysis is that the per capita carbon emission variable is the Granger cause of nuclear energy consumption. This finding suggests that the environmental situation influences atomic energy consumption in the five countries under consideration. Finally, the Granger causality analysis revealed a bidirectional causality relationship between the population variable and environmental degradation.

Following the causality analysis, the parameter estimates of various EKC models are also calculated. These results are summarised in Table 5. According to the literature, it is possible to estimate EKC in multiple ways (Leal & Marques, 2022: 11521). For the inverted U shape, which is generally used to explain the theory, the parameter estimate for the $lny_{it}$ variable should be greater than zero, and the parameter estimate for the $lny_{it}^2$variable should be less than zero. When the parameter estimates of the five models obtained using the CCEMG and CCEPMG methods are evaluated, this inverted U shape is only observed for the CCEPMG estimator of Model (1). For this calculation, the parameter estimate of $lny_{it}^2$ is not statistically significant, and the $R^2$ value is 0.56. The EKC examined in other models are always U-shaped. According to the estimated parameters, economic growth is observed in the five countries, and carbon emissions decrease until a certain income level is reached. Once this minimum level of emissions is attained, carbon emissions increase again as economic growth continues. In the five Kuznets models analysed, the turning point (TP) value for BRICS countries is relatively low except for two values. The TP value is absurdly high in the results obtained with the CCEPMG estimator for Model (1). No country can reach a per capita income at the TP value. However, the model's explanatory power with this high TP value is relatively low. Therefore, this estimation value can be ignored. Another outlier TP value is obtained in the CCEMG estimation of Model (5). Although it represents a relatively reasonable level of per capita income, this TP value cannot be considered an accurate estimate since the control variable in the model is statistically insignificant. In light of all these findings, we can conclude that the EKC for the BRICS countries is U-shaped but has a very short left arm. In fact, according to the CCEMG estimates of Model (2), which is statistically the most successful model according to the estimation results, the Kuznets curve exhibits a shape similar to the one shown in Figure 7. These findings suggest that economic growth continues to exacerbate environmental degradation in the BRICS countries.

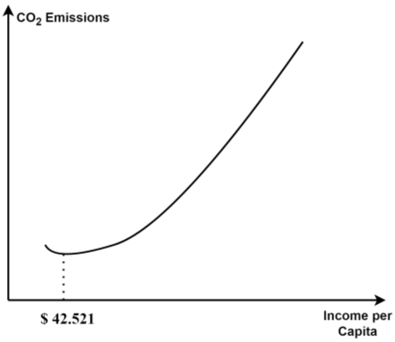
**Table: 5**
**Kuznets Models Estimation Results**

| | Model 1 | | Model 2 | | Model 3 | | Model 4 | | Model 5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | CCEMG | CCEPMG | CCEMG | CCEPMG | CCEMG | CCEPMG | CCEMG | CCEPMG | CCEMG | CCEPMG |
| $lny_{it}$ | -0.601 [0.072*] | 1.199 [0.029**] | -0.705 [0.089*] | -0.443 [0.087*] | -0.629 [0.065*] | -0.469 [0.001***] | -0.672 [0.040**] | -0.419 [0.089*] | -7.390 [0.049**] | -0.694 [0.989] |
| $lny_{it}^2$ | 0.088 [0.039**] | -0.044 [0.103] | 0.094 [0.089*] | 0.073 [0.020**] | 0.091 [0.061*] | 0.093 [0.000***] | 0.103 [0.024*] | 0.079 [0.006***] | 0.433 [0.043**] | 0.095 [0.977] |
| $ne_{it}$ | - | - | 0.073 [0.081*] | 0.152 [0.058*] | - | - | - | - | - | - |
| $me_{it}$ | - | - | - | - | -0.017 [0.719] | -0.191 [0.000***] | - | - | - | - |
| $fdi_{it}$ | - | - | - | - | - | - | 0.017 [0.603] | 0.025 [0.706] | - | - |
| $lnp_{it}$ | - | - | - | - | - | - | - | - | -5.704 [0.586] | 0.600 [0.962] |
| TP | \$30.410 | \$826536.913 | \$42.521 | \$20.785 | \$31.691 | \$12.447 | \$26.105 | \$14.181 | \$5082.137 | \$38.576 |
| $MG\ R^2$ | 0.92 | 0.56 | 0.93 | 0.45 | 0.90 | 0.37 | 0.74 | 0.38 | 0.73 | 0.26 |
| $F$ Stat. | 56.12 [0.000***] | 3.00 [0.000***] | 53.63 [0.000***] | 5.42 [0.000***] | 50.06 [0.000***] | 4.96 [0.000***] | 8.72 [0.000***] | 4.95 [0.000***] | 3.33 [0.000***] | 1.21 [0.230] |
| $CD$ Stat. | -0.77 [0.439] | -1.10 [0.270] | 1.20 [0.231] | -1.55 [0.122] | -0.93 [0.352] | -1.59 [0.111] | -0.47 [0.635] | -0.21 [0.833] | -0.06 [0.953] | -1.71 [0.088*] |

*The dependent variable of all models is $lnce_{it}$.*
*The values in square brackets indicate the p-values of the z-statistics for the parameter estimates, as well as the F and CD statistics calculated for the models.*
*TP refers to the Turning Point level of income per capita, as outlined in the Kuznets Hypothesis.*
****, **, and * indicates statistical significance at 99%, 95%, and 90% confidence leves, respectively.*

Another critical finding indicated by the parameter estimates in Table 5 is that the CCEPMG estimator presents very low $R^2$ values in all four models. It is challenging to derive meaningful and reliable economic insights from these estimation results, which exhibit very low explanatory power. For this reason, focusing on the parameter estimates obtained with the CCEMG estimator, according to Model (1), a 1% increase in per capita income results in a decrease of approximately 0.6% in per capita carbon emissions. This decrease was found to be 0.7% in Model (2), 0.63% in Model (3) and 0.67% in Model (4). It is expected that all these values are close to each other. Another aim of the study's empirical analysis was to measure the effect of selected control variables on carbon emissions. In line with this aim, a 1% increase in the share of nuclear energy in total energy consumption results in a carbon emissions per capita increase of approximately 0.07% for these five countries. In other words, the use of nuclear energy has a negative impact on the environment for these five developing countries. Examining military expenditures as a control variable reveals no statistically significant effect on carbon emissions when using the CCEMG estimator, which has high explanatory power. However, according to the parameter estimates from the CCEPMG estimator, which has a lower $R^2$, a 1% increase in military expenditures as a proportion of total income leads to an approximate 0.2% reduction in carbon emissions in the five countries studied. The parameter estimates of another control variable, FDI, were not found to be statistically significant for any model. In addition to these factors, the population variable, which is considered in IPAT models and included in the model as a control variable, did not have a statistically significant effect on the dependent variable, carbon emissions. Generally, it isn't easy to make structural interpretations for the control variables except for the nuclear energy consumption variable in total energy consumption. The empirical analysis yields two significant findings regarding environmental degradation and carbon dioxide emissions in BRICS countries. First, from very low per capita income levels, environmental degradation increases steadily with income. The second important finding is that only nuclear energy use statistically affects environmental degradation among the control variables added to the Environmental Kuznets model. The parameter estimates of the other control variables are either statistically insignificant or the explanatory power ($R^2$) values of the models in which they are significant are low.

**Figure: 7**
**Shape of Kuznets Curve According to Estimated TP Value of Model (2) with CCEMG Method**




### 4.4. Robustness Check

This study employed environmental Kuznets models because they provide information on turning points. However, ignoring the IPAT model approach is challenging, as it enables the empirical analysis of the relationship between environmental impact factors and economic variables for the first time. For this reason, to better evaluate the findings of our study, the IPAT model was also estimated for the BRICS countries using the same variables, and the results are summarised in Table 6. In the IPAT model, which is constructed and parameter estimates are performed here, the variable of nuclear energy utilisation, which we have already utilised in this study, is used as the technology variable. Countries capable of generating atomic energy have demonstrated the ability to master complex scientific principles, including nuclear chain reactions, radioactive decay, and the management of nuclear waste. Advanced nations with nuclear energy programs typically invest significantly in research and development (R&D) and strong educational and scientific institutions (Pearce, 2012; Kornecki & Wise, 2024).

**Table: 6**
**IPAT Model Estimation Results**

| | $lnp_{it}$ | $lny_{it}$ | $ne_{it}$ | $MG\ R^2$ | $F$ Stat. | CD Stat. |
|---|---|---|---|---|---|---|
| CCEMG | -2.619<br>[0.346] | 0.696<br>[0.076*] | 0.093<br>[0.045**] | 0.95 | 1.970<br>[0.000***] | -1.600<br>[0.111] |
| CCPMG | -0.221<br>[0.003***] | 0.653<br>[0.003***] | 0.146<br>[0.014**] | 0.56 | 6.73<br>[0.000***] | -1.45<br>[0.146] |

*The dependent variable of all models is $lnce_{it}$.*
*The values in square brackets indicate the p-values of the z-statistics for the parameter estimates, as well as the F and CD statistics calculated for the models.*
****, **, and * indicates statistical significance at 99%, 95%, and 90% confidence leves, respectively.*

When the IPAT model with parameter estimates for BRICS countries is analysed, it is observed that the Mean Group estimator provides a high $R^2$ value, but the population variable is not statistically significant. The Pool Mean Group estimator, on the other hand, finds all parameter estimates statistically significant but yields a very low $R^2$ value. The population variable was also statistically insignificant in the Kuznets model estimates. In this case, it can be said that the results of the IPAT model and the results of the Kuznets model support each other. Moreover, the parameter estimates of the population variable in the IPAT model and the Mean Group estimator of the Kuznets model are negative. These results contradict the hypothesis that the population contributes positively to ecological pollution proposed by the IPAT model. Therefore, the effect of the population variable on environmental degradation in the BRICS countries is insignificant due to the statistically negligible and negatively signed parameter estimates.

The effects of nuclear energy variables on environmental degradation, for which parameter estimates are made with the IPAT model, are estimated similarly to those in Kuznets models. The effect of nuclear energy use on carbon emissions is positive and statistically significant, albeit small in magnitude. The effect of another variable, income, should be interpreted carefully in the IPAT and Kuznets models. Both modelling approaches include income in different structural forms. While Kuznets adds the square of income and income to the model, aiming to calculate a turning point for income, the IPAT model directly includes income. For this reason, it is incorrect to make direct comparisons, especially regarding the signs of parameter estimates. However, it can be easily stated that both models reveal that income has a significant impact on environmental degradation. As a result, the IPAT model estimation for the robustness check does not reveal any new findings that contradict the findings of the Kuznets model.

## 5. Discussion and Conclusion

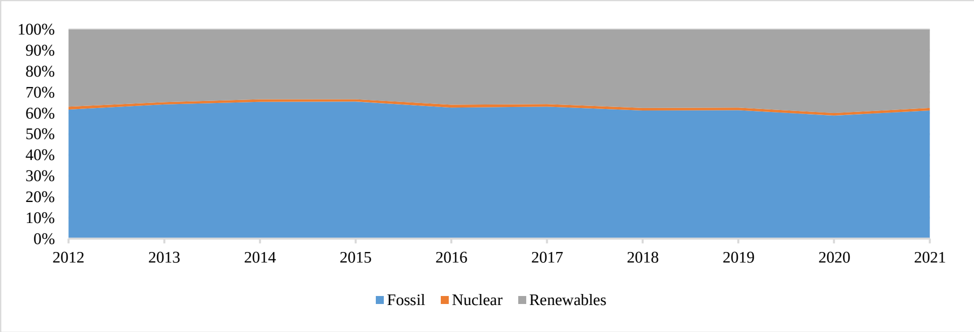
In the empirical analysis for BRICS countries, a prominent group of developing countries, three different model parameters were estimated, along with the classical Kuznets model (Equation (1)), to reveal the impact of military expenditures, nuclear energy use, and foreign direct investments on the environment. According to the findings, contrary to the prediction of the Kuznets theory, the relationship between environmental quality and economic growth was found to be U-shaped for BRICS countries that can produce nuclear energy and have significant defence budgets. Accordingly, the five countries examined do not harm the environment up to a certain level of economic growth; however, when the threshold level of economic growth is exceeded, these countries begin to fail in their environmental protection. Unfortunately, the shape of this relationship remains unchanged, regardless of the use of nuclear energy, defence expenditures, or foreign direct investments.

The findings should be evaluated within the framework of the primary policy issue addressed in our study, which is whether the defence expenditures and nuclear energy use of developing countries contribute to environmental degradation. The findings reveal that defence expenditures do not significantly impact the environmental quality indicator in BRICS countries. It is essential to note that the impact of defence expenditures on the environment remains relatively weak, particularly in this panel data, which also includes two countries, Russia and China, that have significantly invested in their military assets in recent years. It should also be noted that all BRICS countries, especially Russia and China, have their defence industries. Therefore, the defence expenditures of these countries primarily support their defence industries. In light of this fact, it can be inferred that the defence industry activities of the examined countries do not have a significant indirect impact on environmental degradation. It is an important finding that Russia's defence expenditures do not harm the environment, despite the ongoing conflicts with a certain continuity that Russia has experienced since the collapse of the Soviet Union (Chechnya Wars, 1994-2009; Georgia-Russia War, 2008; Ukraine-Russia War, 2020, etc.). In addition, China, which is constantly expanding its military assets due to the global power race, now has the largest navy in the world (US Department of Defense, 2023: 70). The fact that China, with its substantial mass production capacity, does not harm the environment while expanding its military (with the damage being negligible) is a positive empirical finding for the country. The reason for focusing on Russia and China so far is that these two countries meet almost all of their defence needs through their industries due to the embargoes they are subjected to. Other BRICS countries also face geopolitical challenges, although not to the same extent as Russia and China. In particular, India's border disputes with Pakistan and China necessitate the country maintaining its defence expenditures at a significant level. While Brazil faces more internal security challenges, South Africa is perhaps the most peaceful country among the BRICS nations. The relationship between defence expenditures and environmental degradation, which has not been extensively studied in the literature, is found to be quite weak, according to the findings of this study. As long as developing countries are not party to a nuclear war that will cause environmental damage, the environmental damage of hot conflicts in which they will take part to protect their geopolitical interests will not reach serious levels.

Another finding of the empirical analysis is that the foreign direct investments of the developing economies do not have a statistically significant effect on the countries' carbon emissions. The fact that foreign investments do not impact carbon emissions has been analysed from different perspectives in the literature. For example, Zarsky (1999) emphasised the quality of investments and stated the importance of the industrial sectors to which foreign investments are directed. Foreign direct investments cannot be expected to reduce carbon emissions if investments are concentrated in industries with high fossil fuel consumption. This is likely to be the case for the countries we have analysed. Another reason for the lack of a significant relationship between foreign investments and carbon emissions is that governments often do not prioritise environmental regulations in their legal frameworks and lack a robust legal infrastructure to protect the environment. Eskeland and Harrison (2003) argue that countries with stringent environmental laws and regulations may attract foreign investments to areas with high environmental standards. However, developing economies, which rely heavily on foreign investment, may not prioritise whether the activities in areas where foreign investments will be directed are environmentally friendly. Finally, as stated by Zeng and Eastin (2012), investments in advanced economies can bring efficient technologies, which may, in turn, lead to reduced emissions. However, if the incoming technology is outdated or less efficient, it may not have a positive impact on reducing carbon emissions. From this perspective, it is evident that the five developing countries capable of producing nuclear energy, which we subjected to econometric analysis, were unable to achieve efficient technology transfer at a level that would reduce their emission values.

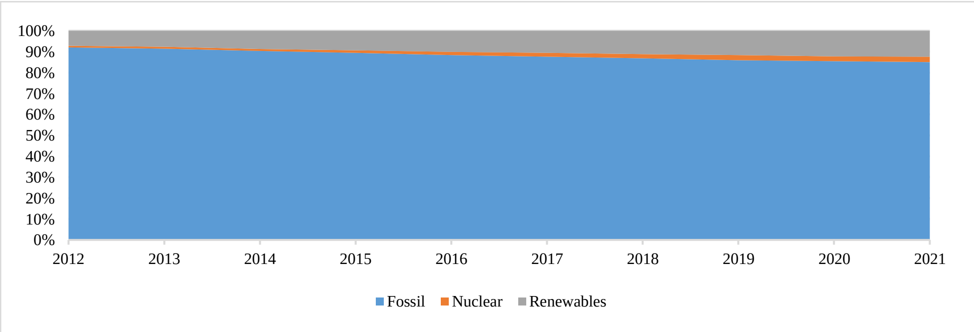
One of the study's significant findings is that the use of nuclear energy has a negative environmental impact in the five developing countries examined. The energy consumption distribution of the BRICS countries, which are capable of producing nuclear energy, may play a key role in this finding.

**Figure: 8**
**Resource Distribution of Energy Consumption in Brazil**



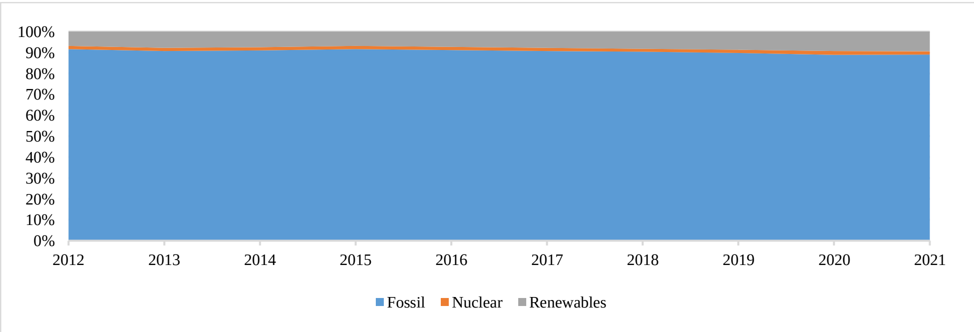

*Source: Authors' calculation based on the U.S. Energy Information Administration Database.*

**Figure: 9**
**Resource Distribution of Energy Consumption in China**



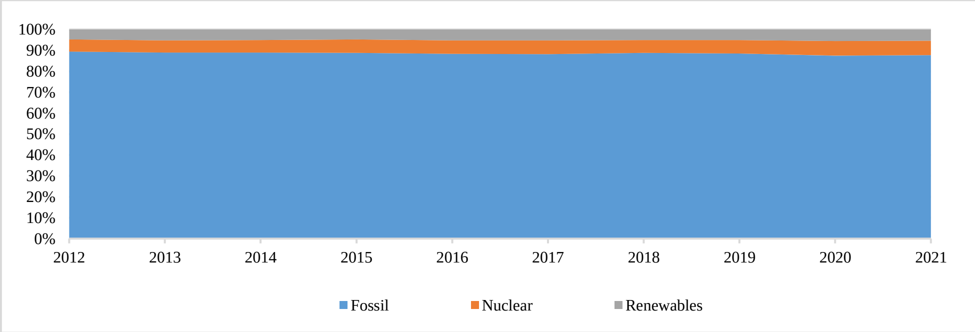

*Source: Authors' calculation based on the U.S. Energy Information Administration Database.*

**Figure: 10**
**Resource Distribution of Energy Consumption in India**



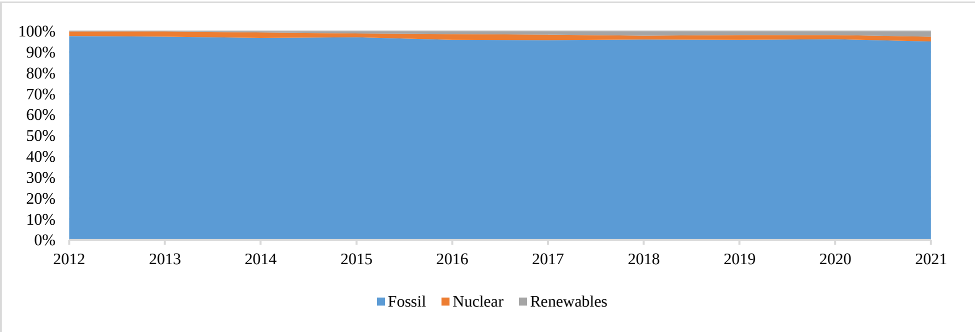

*Source: Authors' calculation based on the U.S. Energy Information Administration Database.*

**Figure: 11**
**Resource Distribution of Energy Consumption in Russia**




*Source: Authors' calculation based on the U.S. Energy Information Administration Database.*

**Figure: 12**
**Resource Distribution of Energy Consumption in South Africa**




*Source: Authors' calculation based on the U.S. Energy Information Administration Database.*

As the graphs above show, when the energy resource distribution of BRICS countries is analysed, the dominant energy source is fossil fuels, which may lead to increased carbon emissions in these countries and, ultimately, to environmental degradation.

When the graphs of energy consumption distribution in BRICS countries using nuclear energy are analysed, fossil fuels are predominant in these countries. This situation means that the carbon emissions released into the atmosphere in these countries remain unchanged, which can lead to environmental deterioration.

It would not be wrong to say that the incomplete institutional structure of the BRICS formation is one of the reasons for this situation. The predominance of fossil fuels in the energy consumption composition of these countries suggests a lack of consensus among nations regarding standard action. Compared to the European Union, which has a similar structure, the BRICS require numerous structural reforms to enhance institutional functioning. The lack of legal texts in the BRICS countries and the inability of the existing ones to function at the point of joint action may undermine the institutionalisation of the BRICS formation. At this point, “Green Keynesian Economics” will be able to develop practical solutions to overcome these shortcomings, providing a new reflection of Keynesian economic thought. Green Keynesian Economics is a combination of environmental economics and Keynesian macroeconomics. It proposes that the state actively intervene in the economy to reduce carbon emissions, the primary source of environmental problems (Harris, 2013: 3).

Considering the political, demographic, and economic structures of the BRICS countries, the active role of states in economic life may have practical consequences for environmental degradation in these countries. These policy recommendations are listed below:

- *Energy Efficiency*: Investing in technological innovations and energy-saving policies to increase energy production and consumption efficiency. By ensuring energy efficiency, unnecessary energy consumption and, thus, carbon emissions can be reduced.
- *Clean Transportation: Support the adoption of electric vehicles and public transportation to reduce dependence on fossil fuels in the transportation* sector. Expanding electric vehicle charging infrastructure is also an important policy.
- *Infrastructure Revision*: Reducing emissions requires developing low-carbon transportation systems, green buildings, and energy-efficient infrastructure. Public investments can finance such projects.
- *Privileging Environmentally Friendly Products in Public Procurement*: Granting privileges to environmentally friendly products in public procurement can reduce carbon emissions and create demand for these products, thereby indirectly encouraging their production.
- *Forest and Land Use*: Afforestation projects and sustainable land use policies can contribute to offsetting carbon emissions. Forests play an important role as carbon sinks.
- *Research and Development*: Support research and development efforts to develop and apply advanced technologies to reduce carbon emissions. Innovative solutions such as carbon capture and storage technologies (CCS) can be considered in this context.
- *Incentives and Subsidies*: Provide financial incentives and subsidies for clean energy technologies, energy efficiency and low-carbon practices. This can accelerate the adoption of innovative technologies.
- *Carbon Pricing*: Implementing mechanisms such as carbon taxes or emissions trading systems can be encouraged to reduce carbon emissions. Such pricing can encourage emitting sectors to develop more sustainable alternatives.

- *Sustainable Investments*: Increased cooperation between the public and private sectors can encourage investments in renewable energy, energy efficiency, and green infrastructure. The state can guide and encourage these investments.
- *Green Employment Programs*: Training and skills development programs can be organised to create new employment opportunities in sectors that reduce carbon emissions. In this way, the labour force is also integrated into the transformation process.
- *Research and Development Funds*: Financial support can be provided for research and development projects to encourage the development of innovative and sustainable technologies.

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