Sosyoekonomi

2026, Vol. 34(70), 101-130

RESEARCH ARTICLE

ISSN: 1305-5577 / e-ISSN: 3149-9775
DOI: 10.17233/sosyoekonomi.2026.04.05
Date Submitted: 17.07.2025
Date Revised: 08.06.2026
Date Accepted: 03.08.2026

The Relationship Between CO_2 Emissions, Economic Growth, Energy Intensity, Urbanisation, Life Expectancy at Birth, And Renewable Energy Consumption in BRICS Countries

Zeynep KÖSE *(https://orcid.org/0000-0002-9494-3098), Hasan Kalyoncu University, Türkiye; zeynep.kose@hku.edu.tr*

Eda DİNERİ *(https://orcid.org/0000-0002-5637-594X), Hasan Kalyoncu University, Türkiye; eda.dineri@hku.edu.tr*

Gözde TUĞAN-MERAL *(https://orcid.org/0000-0002-1918-1249), İstanbul Kent University, Türkiye; gozde.meral@kent.edu.tr*

Yakup DURMAZ *(https://orcid.org/0000-0003-0332-4185), Kilis 7 Aralık University, Türkiye; yakup.durmaz@kilis.edu.tr*

BRICS Ülkelerinde CO_2 Emisyonları, Ekonomik Büyüme, Enerji Yoğunluğu, Kentleşme, Doğumda Beklenen Yaşam Süresi ve Yenilenebilir Enerji Tüketimi Arasındaki İlişki

Abstract

This study examines the relationships between CO_2 emissions and economic growth, energy intensity, life expectancy at birth, urbanisation and renewable energy consumption in the BRICS countries over the period 2000-2022 using panel data analysis. The analysis applied cross-sectional dependence and Delta tests; the stationarity of the series was assessed using the CIPS unit root test, whilst long-run relationships were analysed using the Westerlund cointegration test. Causal relationships were determined using the Dumitrescu-Hurlin panel causality test. The findings indicate the existence of a bidirectional causal relationship between energy intensity, economic growth, life expectancy and CO_2 emissions. Conversely, a unidirectional causal relationship from renewable energy consumption and urbanisation to CO_2 emissions was identified. The results reveal strong and multifaceted interactions between energy structure, economic growth and environmental sustainability in BRICS countries.

Keywords : CO_2 Emissions, Energy Intensity, Life Expectancy, Urbanisation, Renewable Energy, BRICS Countries.

JEL Classification Codes : Q43, Q54, Q56.

Öz

Bu çalışmada, BRICS ülkelerinde 2000-2022 dönemi için CO_2 emisyonları ile ekonomik büyüme, enerji yoğunluğu, doğumda yaşam beklentisi, kentleşme ve yenilenebilir enerji tüketimi arasındaki ilişki panel veri analizi yöntemi kullanılarak incelenmektedir. Analizde yatay kesit bağımlılığı ve Delta testleri uygulanmış; serilerin durağanlığı da CIPS birim kök testi ile değerlendirilmiştir. Değişkenler arasındaki uzun vadeli ilişki, Westerlund eşbütünleme testi kullanılarak analiz edilmiştir. Değişkenler arasındaki nedensellik ilişkisinin test edilmesi için Dumitrescu-Hurlin Nedensellik Testi'ne başvurulmuştur. Elde edilen bulgular, enerji yoğunluğu, ekonomik büyüme, yaşam beklentisi ve CO_2 emisyonları arasında çift yönlü bir nedensel ilişkinin varlığını göstermektedir. Buna karşılık, yenilenebilir enerji tüketimi ve kentleşme ile CO_2 emisyonları arasında tek yönlü bir nedensel ilişki tespit edilmiştir. Sonuçlar, BRICS ülkelerinde enerji yapısı,

ekonomik büyüme ve çevresel sürdürülebilirlik arasında güçlü ve çok yönlü etkileşimlerin bulunduğunu ortaya koymaktadır.

Anahtar Sözcükler : CO_2 Emisyonları, Enerji Yoğunluğu, Yaşam Beklentisi, Kentleşme, Yenilenebilir Enerji, BRICS Ülkeleri.

1. Introduction

In recent years, energy demand has risen significantly globally due to the acceleration of industrialisation, rapid population growth, the expansion of production and consumption activities, and the impact of globalisation. Rising fossil fuel consumption due to energy demand increases carbon levels in the atmosphere, thus leading to global warming, climate change and environmental degradation (Kasman & Duman, 2015; Shuai et al., 2017). The rapid growth of world energy use has also increased concerns about supply problems. Therefore, energy efficiency and conservation and the reduction in carbon emissions (CO_2) caused by energy use have become important issues (Perez-Lombard et al., 2008; Chu & Majumdar, 2012). Along with rising energy consumption, dependence on fossil fuels brings multifaceted challenges, such as high energy intensity, energy security risks, and environmental pollution (Shahbaz, 2015; Ulucak, 2020). In this context, the relationship between energy consumption, economic growth, and environmental degradation has been extensively addressed in the literature. Indeed, studies such as those by Chang et al. (2009), Von (2009), Khan et al. (2014), Arouri et al. (2012), and Shyamal and Rabindra (2004) demonstrate that there is a strong relationship between energy consumption and economic growth, and that this relationship often leads to outcomes that exacerbate environmental degradation.

However, while these studies emphasise that energy consumption is one of the fundamental inputs of economic growth, they also point out that uncontrolled and intensive use of fossil fuels threatens environmental sustainability. Therefore, in recent years, the need to increase the use of renewable energy sources, reduce energy intensity, and adopt low-carbon growth strategies has come to the forefront in the literature. Furthermore, it is stressed that countries' levels of development, energy policies, and structural characteristics should be taken into account to understand the energy-economy-environment relationship more comprehensively.

The relationship between renewable energy consumption and CO_2 emissions holds a significant place in the environmental sustainability literature. Generally, increased use of renewable energy sources contributes to reduced carbon emissions by decreasing dependence on fossil fuels. This allows for the use of lower carbon-intensive technologies in the energy production process, helping to limit environmental degradation. Indeed, many studies in the literature show that renewable energy consumption has a statistically significant effect in reducing CO_2 emissions (Sadorsky, 2009; Apergis & Payne, 2010). However, it is also emphasised that the impact of renewable energy use on emissions may

vary depending on factors such as countries' energy policies, technological advancement levels, and economic structures. Therefore, increasing renewable energy investments and accelerating energy transition processes are critically important for achieving a low-carbon and sustainable growth path.

CO_2 emissions are affected by many factors, such as population growth, energy consumption, urban population growth, and capital accumulation. Increasing population, economic activities, technology, politics, institutions, beliefs, and attitudes are factors that increase greenhouse gas emissions (Dietz & Rosa, 1997). These variables are important in sustainable economic growth (Khan, 2020). In this context, population growth and urbanisation processes, in particular, indirectly increase carbon emissions by increasing energy demand. Increased production and consumption activities intensify energy use and strengthen dependence on fossil fuels. However, the direction of capital accumulation and technological developments plays a significant role in determining the extent of environmental impacts. While the adoption and dissemination of environmentally friendly technologies contribute to reducing carbon emissions, growth models that disregard environmental concerns can accelerate environmental degradation. Urbanisation is one of the basic elements of development. However, rapid urbanisation can also hurt growth by straining existing infrastructure. For example, population growth and rapid urbanisation cause environmental problems, particularly by increasing fossil energy demand. In this case, improving the economic structure and applying advanced technologies are highly important for sustainability. In situations where energy efficiency is low, energy-efficient technologies are limited, and environmental awareness is insufficient, urbanisation increases per capita energy consumption and carbon emissions (Zheng & Walsh, 2019; Lindle, 2013; Fan et al., 2006; Zhang & Lin, 2012). The environmental impacts of urbanisation are not limited solely to negative aspects. Planned and sustainable urbanisation policies can help reduce carbon emissions through increased energy efficiency, the development of public transportation systems, and investments in green infrastructure. In particular, smart city initiatives, the widespread adoption of renewable energy, and the implementation of eco-friendly building technologies play a balancing role in mitigating the environmental impacts of urbanisation.

Along with globalisation, countries entered a transformation process involving urbanisation and infrastructure investments; the transition from agriculture to industry accelerated, and rural-urban migration also increased. The changing population structure with urbanisation first creates differences in lifestyles in terms of clothing, food, housing, and transportation; industrialisation and urbanisation also increase energy consumption. As a result of the widespread use of industrial production, infrastructure development processes and the expansion of the industrial production scale increase CO_2 emissions (Wang et al., 2019; Destek & Ozsoy, 2015; Ahmad et al., 2019). The impact of urbanisation on energy use is not homogeneous among countries and varies depending on the level of development. For low-income countries, urbanisation relatively reduces energy use by providing access to modern fuels rather than using inefficient traditional fuels. In summary, energy use increases with urbanisation across income levels, but the patterns differ. To reduce long-term energy

demand, developing countries should build relatively efficient and sustainable urban infrastructure systems (Poumanyvong & Kaneko, 2010).

Energy is an important input in achieving economic growth and development goals (Shahbaz, 2015), but negative development due to energy consumption poses an obstacle to achieving sustainable economic growth and development in the long run. Especially in developing countries, as energy needs are met, fossil fuel CO_2 emissions have increased (Mensah, 2014; Bacon & Bhattacharya, 2007). The expansion of economic activity leads to increased production volume, a parallel rise in energy consumption, and accelerated urbanisation. However, the reliance on fossil fuels for energy supply in this process increases environmental costs, deepening problems such as air pollution, carbon emissions, and ecological degradation. This situation negatively affects not only environmental sustainability but also social welfare and economic stability. Increased production raises energy consumption and urbanisation. In this case, because energy needs are mostly met from fossil fuels, environmental destruction increases as CO_2 emissions rise. The deterioration of environmental quality and increasing global warming have led to many health problems. In recent years, global warming and environmental and health problems have been important issues that policymakers have focused on. Sulfur dioxide and carbon dioxide emissions from fossil fuel use cause serious environmental pollution (Kırıkkaleli & Kalmaz, 2020; Odusanya et al., 2014). In this context, increasing energy efficiency, raising the share of renewable energy sources in the energy supply, and widespread adoption of low-carbon production technologies are of critical importance. At the same time, strengthening environmental regulations and adopting holistic policy approaches in line with sustainable development goals have become inevitable for both the continuation of economic growth and the protection of environmental quality.

The negative effects of increasing environmental pollution on public health have begun to cause concern worldwide. Environmental pollution is an important factor affecting human health, human life expectancy, and sustainability (Stern, 2006; Rjoub et al., 2021). Health problems arising from environmental pollution increase individual and public healthcare expenditures. Respiratory illnesses and chronic diseases, particularly those caused by air pollution, put pressure on healthcare budgets by raising treatment and care costs. Furthermore, health problems negatively impact individuals' participation in the workforce and productivity, resulting in indirect costs to economic performance. Environmental pollution not only reduces the quality of life. It also increases private and public health expenditures. Health expenditures for emerging health problems constitute an extra expense for both individuals and the state budget. Environmental pollution generally causes respiratory diseases and affects the working life of individuals with deteriorating health, resulting in serious consequences for labour productivity and life expectancy. This situation, directly and indirectly, affects sustainable economic growth and development by decreasing the human capital stock in the long run (Igbinedion, 2019).

Kumari (2025) identified the key determinants of carbon dioxide emissions for BRICS countries using the Autoregressive Distributed Lag (ARDL) model. To this end, economic, demographic, and energy-related variables- including carbon dioxide emissions, access to electricity, renewable energy consumption, fuel imports, access to clean fuel, urban population, and total population- were considered. The study sought to identify long- and short-term relationships among these variables. The researcher emphasised the importance of aligning economic growth with environmental sustainability, ensuring energy efficiency, and reducing fossil fuel consumption within the BRICS framework. However, while the relevant study identified the determinants of carbon dioxide emissions, it used the total population variable to represent demographic structure. In our study, however, we used the life expectancy at birth variable, which is an important indicator of socio-economic development. Life expectancy at birth goes beyond being a demographic indicator; it provides a comprehensive assessment that includes the population's health, income, and living conditions. This significance stems from the variable's role in our study. Life expectancy at birth is a strong indicator of development; it provides important signals not only regarding countries' health systems but also concerning education, living standards, and institutional structures.

The relationships between CO_2 emissions, energy consumption, renewable energy use, life expectancy at birth, and urbanisation form a multidimensional network of interdependent interactions in the literature on sustainable development and the environment-economy. While increasing energy consumption and fossil fuel use directly raise CO_2 emissions, renewable energy consumption plays a critical role in reducing carbon emissions by decreasing reliance on fossil fuels (Sadorsky, 2009; Apergis & Payne, 2010). Urbanisation and population growth intensify environmental pressures by increasing energy demand, while life expectancy at birth can indirectly influence energy consumption and emissions through rising levels of prosperity and health. In this context, while energy consumption and urbanisation emerge as driving factors increasing CO_2 emissions, the implementation of renewable energy and advanced technologies functions as balancing elements. To achieve sustainable development, environmental policies must be integrated with the energy structure, urban planning, and human capital dynamics.

The original value of this study lies not merely in following the existing literature, but in presenting a comprehensive and methodologically consistent framework that advances it in specific ways. The most important point distinguishing this study from others is that few studies have investigated the relationship between life expectancy and CO_2 in BRICS countries. Furthermore, while analysing the determinants of environmental degradation in BRICS countries, the study integrates variables such as economic growth, energy intensity, renewable energy consumption, urbanisation, and life expectancy at birth, which are typically addressed separately in the literature, into a single model. This multidimensional approach distinguishes itself clearly from previous studies by enabling the assessment of environmental impacts not only in terms of economic factors but also in conjunction with social and energy-based dynamics. The study covers the period from 2000

to 2022, which encompasses the effects of the accelerating energy transition, urbanisation, and environmental pressures in BRICS countries in recent years. In particular, the identified unidirectional causal relationship from urbanisation to CO_2 emissions highlights the environmental costs of unplanned urbanisation in developing economies, offering important insights for policymakers. This aspect also holds original value.

2. Literature Review

CO_2 emissions are almost the only variable considered in regulating environmental quality, and many variables increase these emissions (Noshen et al., 2020; Wang et al., 2012). However, recent studies have focused on the impact of life expectancy on reducing carbon emissions.

2.1. Studies on Urbanisation and CO_2 Emissions

After the 1990s, the rapid increase in urbanisation has led to rising energy demand and heightened environmental pollution, prompting numerous studies on the relationship between urbanisation and CO_2 emissions (Behera & Dash, 2017). The results of these studies, however, vary depending on the country, region, city, income level, methodology, and sample period (Poumanyvong & Kaneko, 2010; Shuai et al., 2017).

Early cross-country studies highlighted the positive impact of urbanisation on CO_2 emissions. Parikh and Shukla (1995) analysed 83 developing and developed countries and found that urbanisation increases CO_2 emissions. Similarly, York et al. (2003) reported a global increase in emissions due to urbanisation, while Cole and Neumayer (2004) observed that larger populations and higher urbanisation rates contributed to higher CO_2 emissions across 86 countries from 1975 to 1998. Poumanyvong and Kaneko (2010) confirmed these findings for 99 countries over the period 1975-2005. Conversely, York et al. (2008) found that in the former Soviet Republics, a decline in urbanisation contributed to decreasing CO_2 emissions between 1992 and 2000.

Studies examining regional and income-level variations reveal more nuanced effects. Al-Mulali et al. (2012) reported a positive relationship between urbanisation and CO_2 emissions across seven regions from 1980 to 2018. However, some low-income countries in the early stages of development showed a negative relationship. Zhu et al. (2012) similarly found limited evidence for emerging economies. In MENA countries, Al-Mulali et al. (2013) demonstrated long-term relationships between urbanisation and emissions, with the strength of these relationships varying by income and development levels. Li and Lind (2015) confirmed a positive association in 73 countries when divided into low-, lower-middle-, and high-income groups, whereas Sharma (2011) found that urbanisation reduced CO_2 emissions in 69 countries, particularly in high- and middle-income nations. Lin et al. (2017) further indicated that in non-high-income countries, urbanisation had only a modest effect on CO_2 emissions between 1991 and 2013.

Country-specific studies, particularly on developed and newly industrialised nations, provide additional insights. Liddle and Lung (2010) found a positive relationship between urbanisation and CO_2 emissions in 17 developed countries, while Hossain (2011) observed a long-term reduction in emissions due to urbanisation in newly industrialised countries.

City-level analyses, especially for China, dominate the literature due to its high urbanisation rate and status as the world's largest CO_2 emitter. Zhang and Lin (2012) analysed 29 Chinese provinces from 1995 to 2010 and found that urbanisation increased CO_2 emissions, although the magnitude varied by region. Ma (2015) reported a statistically significant positive impact of urbanisation on energy intensity from 1986 to 2011. Similar results were reported by Wang et al. (2012, 2019), Zhang et al. (2014), Xiangyang and Guiqiu (2011), Su et al. (2018), and Ahmad and Zhao (2018), confirming the consistent positive effect of urbanisation on emissions at the city and provincial levels.

Recent studies focusing on Asian countries, including India and Southeast Asia, also emphasise the role of urbanisation in increasing CO_2 emissions. Behera and Dash (2017) examined the South and Southeast Asia region between 1980 and 2012, showing higher emissions particularly in high-income countries. Abbasi et al. (2020) confirmed similar trends in eight Asian countries from 1982 to 2017, while Nosheen et al. (2020) highlighted the combined impact of urbanisation and energy use on emissions in China, India, and other Asian nations. Siddique et al. (2020) further revealed a bidirectional causality between urbanisation and CO_2 emissions, indicating a reinforcing cycle between urban growth and environmental pressure.

Recent studies on urbanisation and CO_2 emissions in BRICS countries have provided detailed information on the environmental impacts of urban growth. Somoye and Akinwande (2023) examined BRICS-T (BRICS + Türkiye) countries using panel data methods. They found that urban population growth reduced CO_2 emissions in some models, while energy intensity and economic growth contributed to increased emissions. Their findings highlight the importance of sustainable urban planning and the integration of renewable energy for emission reduction. Similarly, Türk and Barışık (2024) analysed the dynamics between urbanisation, economic growth, and CO_2 emissions in BRICS-T countries using panel cointegration and causality analyses. The researchers reported that urbanisation has a stronger effect on CO_2 emissions than economic growth and identified a predominantly bidirectional causality between urbanisation-emissions and growth-emissions relationships, emphasising the need to consider environmental impacts in urban transformation processes. Hlongwane (2026) examined the role of energy transition in BRICS countries in more detail and revealed that changes in the energy mix significantly affect CO_2 emissions, and that energy efficiency policies, when combined with urbanisation management, can alleviate environmental pressures. The study highlighted the critical role of renewable energy adoption in reducing emissions from urbanisation. Taken collectively, these studies demonstrate that urbanisation in BRICS countries is closely intertwined with energy use, economic growth, and emissions, and that effective policy interventions, particularly in

renewable energy use and sustainable urban planning, are vital for achieving long-term emission reductions.

2.2. Studies on Life Expectancy and CO_2 Emissions

A range of interrelated economic, environmental, and social factors determines life expectancy at birth. While existing studies on BRICS economies address economic growth, demographic shifts, and environmental pressures, research that systematically evaluates these parameters together remains extremely limited. Given that BRICS countries account for more than half of the world's population, neglecting population dynamics is of the utmost importance. In this context, Audi et al. (2026) analysed the impact of carbon emissions and globalisation on life expectancy in BRICS countries for the period 1990-2023. Ordinary least squares, fixed-effects models, fully modified ordinary least squares, and quantile regression were applied to examine the static and dynamic relationships among the variables. The study specifically focused on gender-specific inequalities in carbon dioxide emissions and economic growth. Consequently, life expectancy serves as the dependent variable in the study. However, in our study, it was included in the model as an explanatory variable. Zhan et al. (2025) similarly noted that environmental degradation and geopolitical risks have negative consequences on public health through pollution and ecosystem damage. For the BRICS countries, using the CS-ARDL, FMOLS, and DOLS methods over the time period spanning 1993-2022, it was concluded that environmental degradation and geopolitical risks negatively affect life expectancy, while institutional quality and GDP have a positive effect.

Several studies have examined the relationship between life expectancy, CO_2 emissions, economic growth, and health investments across different countries and time periods. Early research by Cervellati and Sunde (2005) highlighted the reciprocal effects of economic development and life expectancy in the historical development of Western countries, emphasising that improvements in health conditions stimulate human capital investments, such as education, which in turn reinforce economic growth. Jayachandran and Ileras-Muney (2009) also underscored that longer life expectancy positively affects education investments, while Oster et al. (2013) reported that life expectancy promotes economic growth through enhanced human capital accumulation.

Empirical analyses of CO_2 emissions and life expectancy reveal mixed effects depending on the country group and period. In selected European Union countries, Balan (2016) found a positive association between CO_2 emissions and life expectancy, while Monsef and Mehrjardi (2015) reported a similar direct relationship for 136 countries. In contrast, studies in oil-exporting and highly polluted countries highlighted negative effects: Assadzadeh et al. (2014) identified a negative impact of CO_2 emissions on life expectancy in eight oil-exporting countries (2000-2010), and Rahman et al. (2022) found a unidirectional causal effect of CO_2 emissions reducing life expectancy across 31 high-pollution countries. Radmehr and Adebayo (2022) also confirmed that CO_2 emissions reduce

life expectancy in Mediterranean countries between 2000 and 2018, whereas economic growth, health expenditures, and improved sanitation positively affect life expectancy.

Country-specific studies further support these findings. Rjoub et al. (2021) examined Türkiye (1960-2018). They reported a positive correlation between life expectancy and both CO_2 emissions and GDP, with unidirectional causality from CO_2 emissions to life expectancy and bidirectional causality between life expectancy and GDP. Similarly, Murthy et al. (2021) found that CO_2 emissions negatively affect life expectancy, whereas economic growth, health expenditures, and life expectancy itself exert positive effects (1992-2017). Erdogan et al. (2019) confirmed that CO_2 emissions reduce life expectancy at birth and increase infant mortality in Türkiye (1971-2016), highlighting the need for renewable energy investments.

Studies examining the role of renewable energy indicate that it can mitigate the negative effects of CO_2 on health. Mutajaba et al. (2021) reported a positive relationship between renewable energy consumption and health expenditures in 28 OECD countries (2002-2018), suggesting that increased renewable energy investments reduce air pollution, improve health services, and stimulate economic growth. Apergis et al. (2018, 2020) showed that renewable energy consumption reduces health expenditures and that there is bidirectional causality between health expenditures and CO_2 emissions across Sub-Saharan Africa and global income groups (1995-2017). Ben Jebli (2016) found similar positive effects of renewable energy on health indicators in Tunisia (1990-2011), whereas CO_2 emissions and railway transportation negatively affected health.

While Ridwan et al. (2026) examine the economic, environmental, and development dimensions of life expectancy in BRICS economies, our study examines life expectancy with environmental stress as a determinant. Kumar et al. (2026) analysed the relationship between climate change and human health and mortality rates in BRICS countries for the 2000-2022 period. The study's findings revealed that climate change has led to serious long-term health problems due to relatively high levels of precipitation and temperature. Consequently, life expectancy has been negatively affected by this development. On the other hand, the study concluded that increases in health expenditures and the growing share of renewable energy consumption contribute to longer life expectancy. However, like the studies developed by Ridwan et al. (2026) and Zhan et al. (2025), this study also focused on potential determinants of life expectancy.

Collectively, these studies indicate that CO_2 emissions generally exert negative effects on life expectancy and health outcomes, particularly in developing, oil-exporting, and highly polluted countries, while economic growth, health investments, and renewable energy consumption serve as mitigating factors. The findings emphasise the importance of integrating environmental policies, renewable energy adoption, and health investment strategies to improve life expectancy and overall human capital.

Sart et al. (2025) analysed the effects of life expectancy, education, and income on CO_2 emissions in BRICS countries using panel integration and causality methods. Their findings show a bidirectional causality between life expectancy and CO_2 emissions, revealing that increases in life expectancy are associated with changes in emissions. While life expectancy and income tend to increase CO_2 levels, education indicators were found to reduce emissions; this highlights the balancing role of human capital in environmental outcomes. This study is one of the few studies that specifically examines the long-term dynamics of life expectancy and environmental impacts in BRICS countries. Kaya et al. (2024) analysed the relationship between CO_2 emissions, economic growth, fossil fuel use, and life expectancy in BRICS countries using the PMG-ARDL method. The results showed a negative relationship between life expectancy and CO_2 emissions. Furthermore, a bidirectional causality has been observed between emissions, economic growth, and fossil fuel consumption; this highlights the intertwined nature of environmental pressures and human well-being in these developing economies. Yeboah et al. (2024) analysed the time-frequency relationships between economic growth, CO_2 emissions, and life expectancy in BRICS countries using a wavelet-based analysis method. They found a positive correlation between CO_2 emissions and life expectancy in these countries. Hlongwane (2025) analysed the adoption of renewable energy in BRICS countries and its effect on life expectancy using panel regression. The results showed that increased renewable energy consumption positively affects life expectancy and also mitigates the negative effects of environmental degradation on health outcomes.

2.3. Studies on Energy Intensity and CO_2 Emissions

Although improvements in global energy intensity continue, it remains important in terms of environmental pollution (Ulucak & Khan, 2020). When literature studies are examined, results are generally obtained that energy intensity increases emissions. Shahbaz et al. (2015) revealed that energy intensity has an increasing impact on CO_2 emissions in most African countries from 1980-2012. Ulucak and Khan (2020), in their study of North America, found that high energy intensity causes pollution, thus increasing CO_2 emissions from 1985 to 2017. Sadorsky (2014) examined 18 emerging countries and found that positive impacts of energy intensity, affluence, and urbanisation increase CO_2 emissions between 1971 and 2009.

The share of BRICS countries in the world population is increasing daily. The energy demand of these countries, whose economies are growing rapidly, is increasing (Akram et al., 2021). Despite rapidly rising economies, they show similar growth in human capital and lag in the human capital index. Zhu et al. (2024) conducted a comprehensive study on combating environmental pollution and reducing energy intensity in the pursuit of sustainable development. In this context, they examined the relationship between energy intensity, the frequency of environmental policies, and the integration of renewable energy in BRICS countries between 1991 and 2021 using cross-sectional regression tests, second-generation unit root tests, and panel cointegration tests. The study's findings reveal that

when institutional quality and research and development capabilities reach a certain threshold, the impact of energy intensity on reducing carbon emissions is strengthened. Consequently, the importance of a comprehensive policy approach for effectively reducing carbon emissions has been emphasised. However, this study has focused solely on the aspects of combating environmental pollution related to energy use and energy intensity. It has overlooked social and demographic impacts such as urbanisation and life expectancy at birth.

Koilakou et al. (2024), who emphasise the need to analyse emissions given their economic and demographic dynamics, examined three BRICS economies, China, India, and Brazil, for the period 2000-2018, incorporating energy intensity, household size, and the number of households into their model. At this point, the researchers emphasised that these indicators differ from population size and play a critical role in carbon dioxide levels due to rising electricity consumption. Consequently, the findings underscore that the cost of increasing the standard of living for a growing population is relatively high emissions. In particular, they noted that incorporating additional socio-demographic factors into an integrated econometric model would offer new perspectives on the relationship between energy, society, and the environment. In this context, taking data limitations into account, variables such as urbanisation and life expectancy at birth were included, in addition to those in the existing literature.

2.4. Studies on Renewable Energy and CO_2 Emissions

Many theoretical and empirical studies have emphasised the critical role of renewable energy consumption in achieving environmental sustainability. A consistent finding across these studies is that increased renewable energy consumption generally reduces CO_2 emissions (Ehigiamusoe & Doğan, 2022; Fu et al., 2021; Kırıkkaleli & Adebayo, 2020; Liu et al., 2020). Recent panel data analyses indicate that the magnitude and significance of this effect often vary by country income level and regional characteristics. For instance, Ehigiamusoe and Doğan (2022) found that renewable energy consumption significantly reduced CO_2 emissions in low-income countries between 1990 and 2016, though the marginal impact differed across countries. Similarly, Khan et al. (2021) reported a significant emission-reducing effect of renewable energy across low-, high-, and global-income panels for the 2002-2019 period. On a global scale, Kırıkkaleli and Adebayo (2020) showed that renewable energy consumption decreased CO_2 emissions between 1995 and 2017, while Haldar and Selti (2020) confirmed the long-term mitigating effect of renewable energy in 39 developing countries during the same period. Conversely, Jebli et al. (2020) noted that, for the 1990-2015 period, renewable energy had a negative impact on emissions in all income groups except low-income countries.

With the rapid economic growth and rising energy demand in BRICS countries, environmental degradation has become a growing concern (Abbas et al., 2022). Recent studies focusing specifically on BRICS countries have provided clear evidence that

renewable energy consumption mitigates CO_2 emissions. For example, Liu et al. (2020), Fu et al. (2021), and Abbas et al. (2022) all reported a significant negative effect of renewable energy on CO_2 emissions, highlighting its potential as a policy tool to balance economic growth with environmental sustainability.

Funda et al. (2024) tested the effects of carbon dioxide emissions, gross domestic product, fossil fuels, renewable energy consumption, and the trade deficit on life expectancy using PMG-ARDL approaches. The research findings concluded that carbon dioxide emissions have a negative and statistically significant effect on life expectancy, whereas per capita GDP and renewable energy consumption have a positive effect on life expectancy. However, as previously stated, life expectancy served as the dependent variable in the studies; the aim was to identify the impact of economic growth and environmental improvement on public health.

Recent empirical findings focusing on BRICS countries confirm the importance of renewable energy and energy efficiency in reducing carbon emissions. Mandimby (2024) analysed the impact of renewable energy on CO_2 emissions in BRICS countries using the PMG-ARDL method. Accordingly, although industrialisation and economic growth create increasing pressure on emissions, it was found that renewable energy consumption significantly reduces emissions in both the short and long term. Addis (2026) examined the Westerlund cointegration and Dumitrescu-Hurlin panel causality tests between renewable energy consumption and CO_2 emissions in the Middle East and BRICS countries. The results show that increases in renewable energy use have a stronger mitigating effect on CO_2 emissions in BRICS countries compared to countries in the Middle East. Furthermore, it highlights the critical role of expanding renewable energy in the energy transition in BRICS countries. Tukhtamurodov et al. (2024) analysed the impact of foreign direct investment, economic growth, trade openness, energy consumption, and renewable energy on carbon dioxide emissions in BRICS countries for the period 1996-2020 using the Panel ARDL and PMG models. The study's findings highlighted the short- and long-term effects of free trade and energy consumption on emissions; the positive short-term effect of foreign investment; and the negative short-term effect of renewable energy. The findings revealed no correlation between economic development and emissions in BRICS countries. Li et al. (2024) analysed the effects of renewable and non-renewable energy sources, natural resource revenues, financial development, and economic growth in BRICS economies for the period 1990-2018 using the Westerlund cointegration test and the cross-sectional dependence (CSD) test. The research findings revealed that economic growth, financial development, and non-renewable energy sources have negative effects on ecological quality, while highlighting the positive impact of renewable energy sources. However, this study addresses environmental damage from an economic perspective for BRICS countries and does not include the demographic aspect in its analysis. Consequently, developing an approach focused solely on energy sources to improve environmental quality amounts to completely disregarding the urbanisation and demographic impacts of the issue and offers an extremely limited conclusion. Similarly, Raza et al. (2025) analysed the relationship between carbon dioxide

emissions, energy consumption, and GDP growth in BRICS countries for the 2009-2022 period using Pedroni cointegration tests and Dumitrescu-Hurlin Granger causality tests. The study concluded that the economic impacts and the potential for environmental damage exhibit an extremely heterogeneous distribution across countries. Ultimately, the importance of investments in clean technologies, energy efficiency, and renewable energy sources for improving environmental quality was emphasised. Erkılıc et al. (2025), on the other hand, analysed the relationship between carbon dioxide emissions, GDP, renewable energy use, and the KOF Globalisation Index in BRICS countries between 1990 and 2020 using cointegration, unit root tests, panel data analysis, and FGLS regression methods. The results indicate that while economic growth and globalisation increase carbon dioxide emissions, the effect of renewable energy use on reducing carbon dioxide emissions is insufficient. Huang et al. (2026), motivated by the need to reduce environmental pollution and harmful emissions in BRICS countries, examined the relationship between renewable energy consumption, global value chains, urbanisation, and carbon dioxide emissions for the period 2000-2018. The study utilised average group and augmented average group estimators; the findings revealed an inverse relationship between renewable energy consumption and carbon dioxide emissions within global value chains, and a positive relationship with urbanisation. This highlights the importance of green initiatives for reducing environmental pressures on BRICS economies. However, this study completely disregarded the impact of demographic factors.

3. Data & Methodology

In this study, the relationship between carbon dioxide (CO_2) emissions, economic growth, life expectancy at birth, energy intensity, urbanisation and renewable energy consumption in the BRICS countries between 2000 and 2022 was tested using panel data analysis. The study first applied cross-sectional dependence and Delta tests. Subsequently, a stationarity test was conducted using the CIPS unit root test. Based on the unit root test results, the long-term relationship between the variables was analysed using the Westerlund Cointegration Test. Finally, the causal relationship was analysed using the Dumitrescu-Hurlin Causality Test. Table 1 below includes information about the variables used in the model. The equation created using data compiled from the World Bank official database is given below. The following equation was derived by taking the natural logarithm of data compiled from the World Bank's official database:

$$lnCO2_{it} = \beta_0 + \beta_1 * lnrew_{it} + \beta_2 * lnurban_{it} + \beta_3 * lnprim_{it} + \beta_4 * life_{it} + \beta_5 * lnGDP_{it} + -\mu_{it}$$

Table: 1
Summary of Variables

Variables	Unit	Symbol	References
CO_2 emissions	(metric tons per capita)	lnCO2	World bank
Urban population	(% of the total population)	lnurban	World bank
Renewable energy consumption	(% of total final energy consumption)	lnrew	World bank
Life expectancy at birth, total	(years)	life	World bank
The energy intensity	(MJ/$2017 PPP GDP)	lnprim	World bank
Economic Growth	GDP (Constant US$)	lnGDP	World Bank

Note: CO_2 is the dependent variable and is used to measure environmental performance in BRICS countries.

While the BRICS countries are undergoing rapid urbanisation, they are also largely responsible for the rise in global energy consumption and carbon emissions. In 2023, the BRICS countries accounted for nearly half of the world's population and 28% of global gross domestic product (GDP). At the same time, there are serious concerns regarding the negative environmental impacts of BRICS countries' dependence on fossil fuels. Because BRICS economies are major exporters in energy-intensive sectors such as iron and steel, aluminium, and fertilisers, which are also high-risk in terms of emissions, this creates a negative situation in terms of high carbon emissions in production processes and global climate goals. The countries' dependence on fossil fuels has led to significant increases in greenhouse gas emissions over time (Udeagha & Ngepah, 2023; UNCTAD, 2025). Consequently, reducing environmental damage has become a major challenge for BRICS countries within this structure characterised by urbanisation and high fossil fuel consumption. Green energy transitions are a critical step for BRICS countries to sustain their economic progress and protect the environment (Hussain et al., 2025). Koilakou et al. (2024) note that China, India, and Brazil, in addition to their geopolitical status at the regional and global levels, possess the potential to create significant environmental impacts as rapidly rising economies. The reason for selecting the BRICS countries in this study is that they form a group of emerging economies characterised by rapid growth within the global economy, rising energy consumption and significant environmental impacts. Furthermore, these countries exhibit common structural characteristics, such as accelerating industrialisation, rising urbanisation rates and increasing energy demand; consequently, carbon dioxide (CO_2) emissions are also rising significantly. Consequently, the BRICS countries present a sample that can be considered homogeneous for analysing the relationship between economic growth and environmental sustainability, yet they also possess distinct development dynamics. This situation enables both cross-sectional comparisons and the derivation of generalisable conclusions in panel data analyses. Furthermore, the high share of these countries in global carbon emissions enhances the study's policy implications.

In this study, the period 2000-2022 was selected as it provides an appropriate time frame covering both data availability and the structural transformations of the variables analysed. This timeframe was chosen specifically because, from the early 2000s onwards, significant changes were observed in economic growth, urbanisation, energy consumption and environmental indicators across the BRICS countries, and because this period also marked the start of the more systematic implementation of renewable energy policies. Furthermore, the 2000-2022 period encompasses critical global developments such as the 2008 Global Financial Crisis and the Paris Climate Agreement, a significant turning point in climate policy. In this context, the 2000-2022 period has been assessed as a balanced and highly representative timeframe that allows for the analysis of both long-term trends and structural shifts.

The variables used in this study were determined based on theoretical frameworks commonly employed in the literature on environmental economics and energy, as well as

previous empirical findings. Accordingly, carbon dioxide emissions (CO_2) are used as the dependent variable in the literature as the most common indicator of environmental degradation (Grossman & Krueger, 1995; IPCC, 2014). Economic growth, meanwhile, is one of the key determinants of environmental pressure, and its relationship with emissions is frequently tested within the framework of the EKC hypothesis (Grossman & Krueger, 1995; Nemat Shafik & Bandyopadhyay, 1992).

Energy intensity is regarded as a key determinant of emissions, as it indicates how much energy an economy uses in its production processes. Higher energy intensity is generally associated with greater fossil fuel consumption and, consequently, higher CO_2 emissions (Sadorsky, 2014). In contrast, renewable energy consumption is a variable shown to support environmental sustainability and reduce emissions (Shahbaz Khan et al., 2015; Apergis & Payne, 2010).

Urbanisation is a significant demographic factor influencing environmental pressure by increasing energy demand and infrastructure use, particularly in developing countries. The literature contains findings suggesting that the effect of urbanisation on CO_2 emissions can be both increasing and decreasing (Poumanyvong & Kaneko, 2010).

Life expectancy at birth is included in the model as an indicator of social welfare and human development. This variable indirectly reflects the relationship between environmental quality and human health and holds a significant place in the literature on sustainable development (United Nations Development Programme, 2020).

In the first stage of the empirical analysis, the CD (cross-sectional dependence) and slope homogeneity tests are performed. Breusch and Pagan's (1980) LM (Lagrange Multiplier) test, CD (Cross Section Dependency) test and CDLM test (Pesaran, 2004), and LMadj (Bias-Adjusted Cross Sectionally Dependent Lagrange Multiplier) tests developed by Pesaran et al. (2008) were applied (Breusch & Pagan, 1980; Pesaran, 2004; Pesaran et al., 2008). The slope homogeneity test (delta test) was used to assess whether units respond at the same level to a shock effect on the panel following cross-sectional dependence.

After the CD and slope homogeneity test, CIPS unit root tests were performed. Since the unit root test results indicated that all variables are first-order integrated (I(1)), a panel cointegration analysis was conducted to examine the long-run relationship among the variables. In this context, the tests include first-generation panel cointegration tests widely used in the literature, such as those by Chihwa Kao (1999) and Peter Pedroni (2004), and second-generation tests, such as the Error Correction Model (ECM) test and the Durbin-Hausman (DH) cointegration test, also developed by Joakim Westerlund (2008).

A fundamental prerequisite for applying the Durbin-Hausman test is that the dependent variable in the cointegration model must not be stationary at the level. In contrast, the independent variables are allowed to be stationary at the level or in the first difference. In this study, in line with these assumptions, the Westerlund (2008) Durbin-Hausman (DH)

panel cointegration test was chosen to analyse the existence of a long-run relationship between the variables.

Following the coefficient estimation, Dumitrescu and Hurlin Causality tests were used to determine the causality. Dumitrescu and Hurlin (2012) test examines whether the causal relationship valid in one country is valid in other countries. In addition, this test is also used if T>N or N>T.

4. Findings

In this section of the study, the information obtained is presented in tables in the order it was gathered.

Table: 2
Descriptive Statistics

	lnCO2	lnprim	lnGDP	life	lnurban	lnrew
Mean	0,6559	0.8129	4.1180	1,8375	1,7562	1.1885
Median	0,8377	0.8407	4.1593	1,8455	1.8002	1.1731
Max.	1,1268	1.0813	4,5870	1,8932	1.9412	1.6989
Min	-0,0269	0.5728	3.4912	1,7317	1.4416	0.5051
Standard Dev.	0.3676	0.1486	0.2878	0.0402	0.1572	0.4196
Skewness	-0,3165	-0.2838	-0.3810	-0,9281	-0.7184	-0.3459
Kurtosis	1,5875	1.8284	2,4417	3,3411	2.1480	1.7393
Jarque Bera	10,3131	8,4092	4,5417	16,9016	10,2153	9,9052
Probability	0,0058	0,0149	0,1034	0,0002	0,0060	0,0070

The descriptive statistics in Table 2 indicate that the variables generally exhibit negative skewness. The kurtosis coefficients below 3 suggest that the data series are platykurtic relative to a normal distribution. According to the results of the Jarque-Bera normality test, the hypothesis of normal distribution is rejected for the lnCO2, lnprim, life, lnurban, and lnrew variables ($p<0.05$), while the assumption of normality cannot be rejected for the lngdp variable ($p>0.05$).

In this section of the study, cross-sectional dependence and the delta test were first applied.

Table: 3
Cross-Sectional Dependence Test

Test	Statistic	Prob.
Breusch -Pagan LM	69.29432	0.0000
Pesaran LM	12.14058	0.0000
Pesaran CD	6.751450	0.0000

Upon examining the table of cross-sectional dependence test results, it is concluded that there is cross-sectional dependence in the series, as the p-values are statistically significant (<0.10). In cross-sectional dependence tests, the Pesaran CD test yields more reliable results when T > N. Accordingly, as the Pesaran CD statistic is also <0.10, cross-sectional dependence has been identified between the variables. Consequently, there is a

statistically significant dependence between the units in the panel. In this case, it would be appropriate to opt for second-generation panel data techniques that account for cross-sectional dependence.

Table: 4
The Result of the Slope Homogeneity Test

	Statistics	Probability
Δtilde	7.551	0,000
Δtilde adj.	9.053	0,000

Given that the p-value in Table 4 is less than 0.10, it is concluded that the slope coefficients are heterogeneous. Accordingly, the effects of the variables included in the model on the dependent variable are not of the same magnitude across the units in the panel, but vary between units.

The study then continues with the CIPS unit root test to determine whether the variables are stationary.

Table: 5
CIPS Unit Root Test

Variable(s)	I(0)	I(1)
lnCO2	-0.930	-2.345**
lnGDP	-0.537	-2.173**
lnprim	-1.316	-3.832**
life	-0.550	-2.477**
lnurban	-0.420	-1.979**
lnrew	-1.006	-3.498**

*Note: The critical values were calculated as -1.57, -1.72, and -1.98 for 10%, 5%, and 1%, respectively. Also, in the table, ** represents stationarity at the first difference I(1).*

Table 5 presents the results of the CIPS unit root test. In the CIPS test, the null hypothesis states that the series contains a unit root, while rejection of the null indicates stationarity. The results show that the variables are not stationary in levels but become stationary after first differencing. Accordingly, carbon dioxide emissions, energy intensity, life expectancy at birth, economic growth, urbanisation, and renewable energy consumption are integrated of order one, I(1). As the unit root test results indicate that the variables are stationary at the first difference, the analysis proceeds with the Westerlund cointegration test.

Table: 6
Westerlund-Durbin-Hausman Cointegration Test

	Statistic		Asym. p-value
DH_g	-20,632	p_valu	0,040*
DH_p	-5,910	p_valu	0,100

The results of the Durbin-Hausman (DH) test developed by Westerlund (2008) are presented in Table 6. In this cointegration test, which accounts for cross-sectional dependence, the panel statistic (DH_p) is analysed when the coefficients in the panel are

homogeneous, whilst the group statistic (DH_g) is interpreted when the coefficients are heterogeneous. As there is heterogeneity and cross-sectional dependence in this study, the interpretation is based on the DH_g and Asym. p-value; consequently, given that the probability value is significant, it has been concluded that a cointegration relationship exists.

Finally, the Dumitrescu-Hurlin Causality Test was applied to examine the causal relationship between the variables.

Table: 7
Dumitrescu-Hurlin Causality Test

	W-Stat	Z- Stat	Prob.
lnprim-lnCO2	4.78052	2.11364	0.0345**
lnCO2- lnprim	8.65776	5.39849	0.0007*
lnGDP-lnCO2	4.23186	1.64880	0.0992***
lnCO2-lnGDP	4.60320	1.96341	0.0496**
life-lnCO2	4.83215	2.15738	0.0310**
lnCO2-life	15.5068	11.2011	0.0000*
lnurban-lnCO2	4.47103	1.85143	0.0641***
lnCO2-lnurban	2.29726	0.00978	0.9922
lnrew-lnCO2	4.51281	1.88683	0.0592***
lnCO2-lnrew	1.10279	0.3162	0.3162

*Note: * p<0.01, ** p<0.05, *** p<0.10.*

Upon examining the table containing the results of the Dumitescu-Hurlin Causality Test, which assesses the causal relationship between variables, a bidirectional causal relationship was identified between energy intensity and CO_2 emissions. This finding is consistent with studies highlighting the reciprocal interaction between energy efficiency and environmental impact. Sadorsky (2014) states that an increase in energy intensity raises emissions, but at the same time, environmental pressures are driving countries to improve energy efficiency. In this context, both the energy-dependent growth structure and increasing environmental regulations in BRICS countries explain this bidirectional relationship.

A bidirectional causal relationship has been identified between life expectancy at birth and carbon dioxide emissions. These results were previously reported by Jayachandran and Ileras-Muney (2009), Monsef and Mehrjardi (2015), Balan (2016), Murthy et al. (2021), Kaya (2024) and Sart et al (2025).

A reciprocal causal relationship has also been identified between economic growth and carbon dioxide emissions. Studies by Mikayilov et al. (2018) and Dinda (2004) also demonstrate a reciprocal interaction between economic growth and CO_2 emissions. In this context, the findings for the BRICS countries indicate that economic growth increases emissions, whilst environmental pressures, in turn, influence growth policies and the transformation of energy choices.

Furthermore, a unidirectional causal relationship has been identified between renewable energy consumption and carbon dioxide emissions. Apergis and Payne (2010) and Shahbaz et al. (2015) have empirically demonstrated that renewable energy consumption reduces CO_2 emissions by decreasing reliance on fossil fuels. In BRICS

countries, this finding also demonstrates the impact of energy transition policies on environmental quality. The findings of this study are supported by the results of studies conducted by Jebli et al. (2020), Liu et al. (2020), Mandimby (2024), and Addis (2026).

A unidirectional causal relationship has also been identified between urbanisation and carbon dioxide emissions. This finding is consistent with the literature suggesting that urbanisation increases environmental pressure. Poumanyvong and Kaneko (2010) demonstrate that urbanisation increases energy consumption and, consequently, emissions, particularly in developing countries. Rapid and unplanned urbanisation in BRICS countries supports this finding by increasing energy demand from transport, housing and industry. Findings from studies by Ang et al. (2014), Xiangyang and Guiqiu (2011), Su et al. (2018), Ahmad and Zhao (2018), Akinwande (2023), and Türk and Barısık (2024) also confirm the relationship between urbanisation and CO_2 emissions.

5. Conclusion and Policy Implications

In this study, the relationship between carbon dioxide emissions and economic growth, life expectancy at birth, urbanisation, renewable energy consumption, and energy intensity in BRICS countries between 2000 and 2022 was tested using panel data analysis. First, cross-sectional dependence and the delta test were applied. Cross-sectional dependence and heteroskedasticity were detected. In line with these results, the CIPS unit root test, a second-generation unit root test, was applied, and it was determined that all variables were I(1) stationary in first-difference form. Consistent with this result, the long-run relationship among the variables was analysed using the Westerlund D.H. test, and a long-run relationship was found to exist among the variables. Finally, the causal relationship among the variables was analysed using the Dumitrescu-Hurlin Causality Test. According to this, a bidirectional causal relationship was found between energy intensity and CO_2. Similarly, a reciprocal causal relationship was found between economic growth and CO_2, as well as between life expectancy at birth and CO_2. Finally, a one-way causal relationship from urbanisation to CO_2 was identified.

Environmental problems such as global warming and climate change caused by the deterioration of the CO_2 emission balance in the atmosphere have serious effects on natural ecosystems. In addition to increasing the risk to humanity in the future (Shuai et al, 2017), economic, social, health, demographic, etc., have negative effects on many areas. Countries take measures to reduce CO_2 emissions, which are important for ensuring sustainability. The use of fossil energy increases energy intensity and CO_2 emissions. Although energy intensity decreases daily, it is still an important factor in environmental degradation. An increase in consumer demand due to population growth stimulates production and increases energy consumption. Urbanisation, which has been rapidly increasing in recent years, is one of the factors affecting CO_2 emissions. The increase in the urban population as a result of migration from rural areas to cities has also led to an increase in energy consumption. Unplanned urbanisation increases CO_2 emissions and poses a threat to global warming and climate.

Countries can reduce carbon emissions by increasing financial support for technological innovation to increase the production of renewable energy (Shuai et al., 2017). A sustainable green economy can be achieved through technological innovations, particularly (Su, 2020) environmentally friendly technologies in energy (Hao, 2021). An improved quality of life will lead to an increase in life expectancy. For this purpose, it is necessary to strengthen strategies and policies to increase investments in renewable energy sources.

Taken together, these findings show a reciprocal and dynamic interaction between environmental degradation and economic and social indicators in BRICS countries. In particular, the bidirectional relationship between energy intensity and CO_2 emissions demonstrates that energy efficiency policies play a critical role in environmental sustainability. Similarly, the reciprocal relationship between economic growth and emissions reveals that growth processes can incur environmental costs, highlighting the importance of sustainable growth strategies. The bidirectional relationship between life expectancy at birth and CO_2 reflects the impact of environmental quality on human health and the relationship between health indicators and environmental pressures. The unidirectional causality identified from urbanisation to CO_2 emissions points to the increasing effect of rapid and unplanned urbanisation on environmental pressures.

Policy recommendations to be developed within the framework of the sustainable development paradigm focus on promoting technological innovations aimed at improving energy efficiency and expanding the renewable energy portfolio. In this context, strategically supporting low-carbon production technologies is of vital importance to maintain a balance between economic growth targets and environmental sustainability.

In urban development processes as well, sustainable urban planning models that respect ecological balances, resilient infrastructure investments, and decarbonization policies aimed at reducing emissions should be prioritised. Ultimately, integrating public health and environmental policies through a holistic approach is critical for achieving a sustainable socio-economic transformation.

For future studies, it is suggested that comparative analyses of different country groups be conducted, and that additional variables such as institutional quality, technological innovations, or environmental policies be included in the model. Furthermore, testing for nonlinear relationships, considering structural breaks, and using alternative panel data methods will make significant contributions to the literature. In addition, detailed country-specific analyses and a deeper examination of heterogeneous structures offer an important research area for future studies.

References

Abbas, S. et al. (2022), "The effect of renewable energy development, market regulation, and environmental innovation on CO_2 emissions in BRICS countries", *Environmental Science and Pollution Research*, 29(39), 59483-59501.

Abbasi, M.A. et al. (2020), "Urbanization and energy consumption effects on carbon dioxide emissions: evidence from Asian-8 countries using panel data analysis", *Environmental Science and Pollution Research*, 27, 18029-18043.

Addis, A.K. (2026), "The impact of renewable energy on CO_2 emissions in Middle Eastern and BRICS economies", *Humanities and Social Sciences Communications*, 13, 194.

Ahmad, M. et al. (2018), "Empirics on linkages among industrialization, urbanization, energy consumption, CO_2 emissions and economic growth: a heterogeneous panel study of China", *Environmental Science and Pollution Research*, 25(30), 30617-30632.

Ahmad, M. et al. (2019), "Revealing stylized empirical interactions among construction sector, urbanization, energy consumption, economic growth and CO_2 emissions in China", *Science of the Total Environment*, 657, 1085-1098.

Ahmed, Z. & Z. Wang (2019), "Investigating the impact of human capital on the ecological footprint in India: An empirical analysis", *Environmental Science and Pollution Research*, 26(26), 26782-26796.

Akram, R. et al. (2021), "Heterogeneous effects of energy efficiency and renewable energy on economic growth of BRICS countries: A fixed effect panel quantile regression analysis", *Energy*, 215, 119019.

Al-Mulali, U. et al. (2012), "Exploring the bidirectional long-run relationship between urbanization, energy consumption, and carbon dioxide emission", *Energy*, 46(1), 156-167.

Al-Mulali, U. et al. (2013), "Exploring the relationship between urbanization, energy consumption, and CO_2 emission in MENA countries", *Renewable and Sustainable Energy Reviews*, 23, 107-112.

Apergis, N. & J.E. Payne (2010), "Renewable energy consumption and economic growth: Evidence from a panel of OECD countries", *Energy Policy*, 38(1), 656-660.

Apergis, N. et al. (2018), "Does renewable energy consumption and health expenditures decrease carbon dioxide emissions? Evidence for sub-Saharan Africa countries", *Renewable Energy*, 127, 1011-1016.

Apergis, N. et al. (2020), "Health care expenditure and environmental pollution: a cross-country comparison across different income groups", *Environmental Science and Pollution Research*, 27(8), 8142-8156.

Arouri, M.E. et al. (2012), "Energy consumption, economic growth and CO_2 emissions in Middle East and North African countries", *Energy Policy*, 45, 342-349.

Asif, M. et al. (2015), "An empirical investigation of the relationship between economic growth, urbanization, energy consumption, and CO_2 emission in GCC countries: a panel data analysis", *Asian Social Science*, 11(21), 270-284.

Assadzadeh, A. et al. (2014), "The Impact of Environmental Quality and Pollution on Health Expenditures: A Case Study of Petroleum Exporting Countries", in: *Proceedings of the 29th International Business Research Conference*, November 24-25, Australia: Sydney.

Audi, M. et al. (2025), "CO_2 emissions, globalization, and health: A dynamic panel analysis of life expectancy in BRICS", *Environment, Development and Sustainability*, https://doi.org/10.1007/s10668-025-06964-0

Bacon, R.W. & S. Bhattacharya (2007), "Growth and CO_2 Emissions: How Do Different Countries Fare?", *Environment Working Paper Series*, No: 113.

Balan, F. (2016), "Environmental quality and its human health effects: A causal analysis for the EU-25", *International Journal of Applied Economics*, 13(1), 57-71.

Baltagi, B.H. (2008), *Econometric Analysis of Panel Data*, John Wiley & Sons.

Bano, S. et al. (2018), "Identifying the impacts of human capital on carbon emissions in Pakistan", *Journal of Cleaner Production*, 183, 1082-1092.

Bashir, et al. (2019), "The Causality between Human Capital, Energy Consumption, CO_2 Emissions, and Economic Growth: Empirical Evidence from Indonesia", *International Journal of Energy Economics and Policy*, 9(2), 98-104.

Behera, S.R. & D.P Dash (2017), "The effect of urbanization, energy consumption, and foreign direct investment on the carbon dioxide emission in the SSEA (South and Southeast Asian) region", *Renewable and Sustainable Energy Reviews*, 70, 96-106.

Breusch, T.S. & A.R. Pagan (1980), "The Lagrange Multiplier Test and Its Applications to Model Specification in Econometrics", *The Review of Economic Studies*, 47(1), 239-253.

Broadstock, D.C. et al. (2016), "Efficiency snakes and energy ladders: a (meta-) frontier demand analysis of electricity consumption efficiency in Chinese households", *Energy Policy*, 91, 383-396.

Cervellati, M. & W. Sunde (2005), "Human Capital Formation, Life Expectancy, and the Process of Development", *The American Economic Review*, 95(5), 1653-1672.

Chang, T.H. et al. (2009), "Threshold effect of the economic growth rate on the renewable energy development from a change in energy price: evidence from OECD countries", *Energy Policy*, 37, 5796-5802.

Cheng, Y. & X. Yao (2021), "Carbon intensity reduction assessment of renewable energy technology innovation in China: A panel data model with cross-section dependence and slope heterogeneity", *Renewable and Sustainable Energy Reviews*, 135, 110157.

Chester, M.V. et al. (2014), "Positioning Infrastructure and Technologies for Low-Carbon Urbanization", *Earth's Future*, 2(10), 533-547.

Chu, S. & A. Majumdar (2012), "Opportunities and challenges for a sustainable energy future", *Nature*, 488(7411), 294-303.

Churchill, S.A. et al. (2019), "R&D intensity and carbon emissions in the G7: 1870-2014", *Energy Economics*, 80, 30-37.

Cole, M.A. & E. Neumayer (2004), "Examining the impact of demographic factors on air pollution", *Population and Environment*, 26(1), 5-21.

Cole, M.A. et al. (2005) "Industrial characteristics, environmental regulations and air pollution: An analysis of the UK manufacturing sector", *J Environ Econ Manage*, 50(1), 121-143.

Démurger, S. & M. Fournier (2011), "Poverty and firewood consumption: a case study of rural households in northern China", *China Econ. Rev.*, 22, 512-523.

Destek, M.A. & F.N. Ozsoy (2015), "Relationships between economic growth, energy consumption, globalization, urbanization and environmental degradation in Turkey", *International Journal of Energy and Statistics*, 03(04), 1550017.

Destek, M.A. (2018), "Çevresel Kuznets eğrisi hipotezinin Türkiye için incelenmesi: STIRPAT modelinden bulgular", *C.Ü. İktisadi ve İdari Bilimler Dergisi*, 19(2), 268-283.

Dietz, T. & E.A. Rosa (1994), "Rethinking the environmental impacts of population, affluence and technology", *Human Ecology Review*, 1(2), 277-300.

Dietz, T. & E.A. Rosa (1997), "Effects of Population And Affluence on CO_2 Emissions", *Proceedings of the National Academy of Sciences*, 94(1), 175-179.

Dinda, S. (2004), "Environmental Kuznets curve hypothesis: A survey", *Ecological Economics*, 49(4), 431-455.

Dong, K. et al. (2018), "Energy intensity and energy conservation potential in China: a regional comparison perspective", *Energy*, 155, 782-795.

Dumitrescu, E.I. & C. Hurlin (2012), "Testing For Granger Noncausality in Heterogeneous Panels", *Economic Modeling*, 29(4), 1450-1460.

Ehigiamusoe, K.U. & E. Dogan (2022), "The role of interaction effect between renewable energy consumption and real income in carbon emissions: evidence from low-income countries", *Renewable and Sustainable Energy Reviews*, 154, 111883.

Ehrlich, P.R. & J.P. Holdren (1971), "Impact of population growth", *Science*, 171(3977), 1212-1217.

Erdoğan, S. et al. (2019), "The relationship between CO_2 emissions and health indicators: The case of Turkey", *Econ Lett*, 6(1), 28-39.

Erkılıç, E. et al. (2025), "Renewable Energy Solution to Carbon Emissions: BRICS Countries in the Grip of Globalization and Economic Growth", *Sustainability*, 17(9), 4117.

Ewing, R. & F. Rong (2008), "The impact of urban form on US residential energy use", *Hous. Policy Debate*, 19(1), 1-30.

Fan, Y. et al. (2006), "Analyzing impact factors of CO_2 emissions using the STIRPAT model", *Environmental Impact Assessment Review*, 26, 377-395.

Farsi, M. et al. (2007), "Fuel choices in urban Indian households", *Environment and Development Economics*, 12(6), 757-774.

Fu, Q. et al. (2021), "Impact of renewable energy on economic growth and CO_2 emissions evidence from BRICS countries", *Processes*, 9(8), 1281.

Goldewijk, K. (2005), "Three Centuries of Global Population Growth: A Spatial Referenced Population Density Database for 1700-2000", *Population and Environment*, 26(5), 343-367.

Grossman, G.M. & A.B. Krueger (1995), "Economic growth and the environment", *The Quarterly Journal of Economics*, 110(2), 353-377.

Hao, L.N. et al. (2021), "Green growth and low carbon emission in G7 countries: How critical the network of environmental taxes, renewable energy and human capital is?", *Science of the Total Environment*, 752, 141853.

Hartwick, J.M. (1977), "Intergenerational equity and the investing of rents from exhaustible resources", *American Economic Review*, 67(5), 972-974.

He, X. & D. Reiner (2016), "Electricity demand and basic needs: empirical evidence from China's households", *Energy Policy*, 90, 212-221.

Hlongwane, N.W. & H. Khobai (2026), "The Impact of Energy Transition on CO_2 Emissions in BRICS Nations: Evidence from Linear and Nonlinear Approaches", *Sustainability*, 18(6), 3109.

Hlongwane, T. (2025), "Renewable energy consumption and life expectancy in BRICS countries: Panel regression evidence", *Renewable Energy*, 210, 1234-1248.

Hossain, M.S. (2011), "Panel estimation for CO_2 emissions, energy consumption, economic growth, trade openness and urbanization of newly industrialized countries", *Energy Policy*, 39(11), 6991-6999.

Huang, H. et al. (2026), "Renewable energy and global value chains: catalysts for reducing carbon emissions in BRICS countries", *Polish Journal of Environmental Studies*, 35(1), 657-671.

Hussain, I. et al. (2025), "Economic policy uncertainty and green energy in BRICS: Impacts on sustainability", *Energy*, 317, 134717.

Igbinedion, S.O. (2019), "Environmental Emissions and Life Expectancy Nexus: Further Evidence from Nigeria", *Annals of the University of Petroşani, Economics*, 19(1), 115-128.

IPCC Intergovernmental Panel on Climate Change (2014), *Climate Change 2014: Synthesis Report*, Geneva: IPCC.

Jayachandran, S. & A. Lleras-Muney (2009), "Life expectancy and human capital investments: evidence from maternal mortality declines", *The Quarterly Journal of Economics*, 124(1), 349-397.

Jebli, M.B. (2016), "On the causal links between health indicator, output, combustible renewables and waste consumption, rail transport, and CO_2 emissions: the case of Tunisia", *Environmental Science and Pollution Research*, 23(16), 16699-16715.

Jebli, M.B. et al. (2020), "Renewable energy, CO_2 emissions and value added: Empirical evidence from countries with different income levels", *Structural Change and Economic Dynamics*, 53, 402-410.

Jones, D.W. (1991), "How urbanization affects energy-use in developing countries", *Energy Policy*, 19(7), 621-630.

Kao, C. (1999), "Spurious regression and residual-based tests for cointegration in panel data", *Journal of Econometrics*, 90(1), 1-44.

Kasman, A. & Y.S. Duman (2015), "CO_2 emissions, economic growth, energy consumption, trade and urbanization in new EU member and candidate countries: A panel data analysis", *Economic Modeling*, 44, 97-103.

Kaya, F. et al. (2024), "Energy choices to health outcomes: A multidimensional analysis of risk in BRICS via PMG-ARDL approach", *PLOS One*, 19(12), e0310558.

Ketenci, N. (2018), "The environmental Kuznets curve in the case of Russia", *Russian Journal of Economics*, 4(3), 249-265.

Khan, I. et al. (2021), "Renewable energy consumption and local environmental effects for economic growth and carbon emission: evidence from global income countries", *Environmental Science and Pollution Research*, 29, 13071-13088.

Khan, M. (2020), "CO_2 emissions and sustainable economic development: New evidence on the role of human capital", *Sustainable Development*, 28(5), 1279-1288.

Khan, M.A. et al. (2014), "Global estimates of energy consumption and greenhouse gas emissions. Renew", *Sustain. Energy Rev*., 29, 336-344.

Khanna, N.Z. et al. (2016), "Effects of demand side management on Chinese household electricity consumption: Empirical findings from Chinese household survey", *Energy Policy*, 95, 113-125.

Khattak, S.I. et al. (2020), "Exploring the impact of innovation, renewable energy consumption and income on CO_2 emissions: new evidence from the BRICS economies", *Environmental Science and Pollution Research*, 27(12), 13866-13881.

Kirikkaleli, D. & D.B. Kalmaz (2020), "Testing the moderating role of urbanization on the environmental Kuznets curve: Evidence from an emerging market", *Environ. Sci. Pollut. Res*., 27, 38169-38180.

Kirikkaleli, D. & T.S. Adebayo (2021), "Do renewable energy consumption and financial development matter for environmental sustainability? New global evidence", *Sustainable Development*, 29(4), 583-594.

Koilakou, E. et al. (2024), "Social and economic driving forces of recent CO_2 emissions in three major BRICS economies", *Scientific Reports*, 14(1), 8047.

Kónya, L. (2006), "Exports and growth: Granger causality analysis on OECD Countries with a panel data approach", *Econ Model*, 23, 978-992.

Kumar, K.K. (2026), "Exploring the Impact of Climate Change on Life Expectancy and Youth Death in BRICS Countries: Empirical Evidence Through the Pooled Mean Group Approach", in: *Climate Action and Sustainable Development Goals* (92-113), CRC Press.

Kumari, N. (2025), "Determinants of Carbon Dioxide Emissions in BRICS Nations: An Empirical Analysis", *International Research Journal of Economics and Management Studies*, 4(12), 108-114.

Levin, A. et al. (2002), "Unit Root Tests in Panel Data: Asymptotic and Finite- Sample Properties", *Journal of Econometrics*, 108(1), 1-24.

Li, B. et al. (2015), "Using the STIRPAT model to explore the factors driving regional CO_2 emissions: A case of Tianjin, China", *Natural Hazards*, 76(3), 1667-1685.

Li, K. & B. Lin (2015), "Impacts of urbanization and industrialization on energy consumption/CO_2 emissions: Does the level of development matter?", *Renewable and Sustainable Energy Reviews*, 52, 1107-1122.

Li, P. & Y. Ouyang (2019), "The dynamic impacts of financial development and human capital on CO_2 emission intensity in China: An ARDL approach", *Journal of Business Economics and Management*, 20(5), 939-957.

Li, S. et al. (2024), "Moving towards a sustainable environment in the BRICS economies: What are the effects of financial development, renewable energy and natural resources within the LCC hypothesis?", *Resources Policy*, 88, 104457.

Liddle, B. & S. Lung (2010), "Age-structure, urbanization and climate change in developed countries: revisiting STIRPAT for disaggregated population and consumption-related environmental impacts", *Popul Environ*, 31(5), 317-343.

Liddle, B. (2013), "The energy, economic growth, urbanization nexus across development: Evidence from heterogeneous panel estimates robust to cross-sectional dependence", *Energy*, 34(2), 223-244.

Lin, S. et al. (2017), "Impacts of urbanization and real economic development on CO_2 emissions in non-high income countries: Empirical research based on the extended STIRPAT model", *Journal of Cleaner Production*, 166, 952-966.

Liu, J.L. et al. (2020), "Do real output and renewable energy consumption affect CO_2 emissions? Evidence for selected BRICS countries", *Energies*, 13(4), 960.

Ma, B. (2015), "Does urbanization affect energy intensities across provinces in China? Long-run elasticities estimation using dynamic panels with heterogeneous slopes", *Energy Economics*, 49, 390-401.

Mahmood, N. et al. (2019), "Renewable energy, economic growth, human capital and CO_2 emission: an empirical analysis", *Environmental Science and Pollution Research*, 26(20), 20619-20630.

Manderson, E. & R. Kneller (2012), "Environmental regulations, outward FDI and heterogeneous firms: are countries used as pollution havens?", *Environmental and Resource Economics*, 51(3), 317-352.

Mandimby, A.S. (2024), "Effect of renewable energy on CO_2 emissions in BRICS countries", *Quantitative Economics and Management Studies*, 5(2), 372-386.

Martínez-Zarzoso, I. & A. Maruotti (2011), "The impact of urbanization on CO_2 emissions: evidence from developing countries", *Ecological Economics*, 70(7), 1344-1353.

Martínez-Zarzoso, I. et al. (2007), "The impact of population on CO_2 emissions: evidence from European countries", *Environmental and Resource Economics*, 38(4), 497-512.

Mehta, D. & M.A. Shah (2024), "BRICS carbon emissions: Asymmetric impact of energy mix, financial development, and digitalization", *Environmental and Development Economics*, 10(1), 2418162.

Mensah, J.T. (2014), "Carbon Emissions, Energy Consumption and Output: A Threshold Analysis on the Causal Dynamics in African Economies", *Energy Policy*, 70, 172-182.

Mikayilov, J.I. et al. (2018), "Carbon emissions and economic growth: An empirical investigation of Azerbaijan", *Energy Policy*, 115, 255-262.

Monsef, A. & A.S. Mehrjardi (2015), "Determinants of Life Expectancy: A Panel Data Approach", *Asian Economic and Financial Review*, 5(11), 1251-1257.

Mujtaba, G. & S.J.H. Shahzad (2021), "Air pollutants, economic growth and public health: implications for sustainable development in OECD countries", *Environmental Science and Pollution Research*, 28(10), 12686-12698.

Murthy, U. et al. (2021), "The Relationships Between CO_2 Emissions, Economic Growth And Life Expectancy", *The Journal of Asian Finance, Economics and Business*, 8(2), 801-808.

Nazlıoğlu, Ş. (2010), "Makro İktisat Politikalarının Tarım Sektörü Üzerindeki Etkileri: Gelişmiş Ve Gelişmekte Olan Ülkeler İçin Bir Karşılaştırma", *Doctoral Dissertation*, T.C. Erciyes Üniversitesi Sosyal Bilimler Enstitüsü, Kayseri.

Nejat, P. et al. (2015), "A global review of energy consumption, CO_2 emissions and policy in the residential sector (with an overview of the top ten CO_2 emitting countries)", *Renewable and Sustainable Energy Reviews*, 43, 843-862.

Newman, P.W.G. & J.R. Kenworthy (1989), "Gasoline consumption and cities", *J.Am.Plan.Assoc.*, 55, 24-37.

Nosheen, M. et al. (2020), "Analyzing extended STIRPAT model of urbanization and CO_2 emissions in Asian countries", *Environmental Science and Pollution Research*, 27(36), 45911-45924.

Odusanya, A.I. et al. (2014), "Environmental Quality and Health Care Spending in Nigeria", *Fountain Journal of Management and Social Sciences*, 3(2), 57-67.

Oster E. et al. (2013), "Limited Life Expectancy, Human Capital and Health Investments", *American Economic Review*, 103(5), 1977-2002.

Pablo-Romero, M. del P. & A. Sánchez-Braza (2015), "Productive energy use and economic growth: Energy, physical and human capital relationships", *Energy Economics*, 49, 420-429.

Pachauri, S. & L. Jiang (2008), "The household energy transition in India and China", *Energy Policy*, 36, 4022-4035.

Parikh, J. & V. Shukla (1995), "Urbanization, energy use and greenhouse effects in economic development: Results from a cross-national study of developing countries", *Global Environmental Change*, 5(2), 87-103.

Pedroni, P. (2004), "Panel cointegration: Asymptotic and finite sample properties of pooled time series tests with an application to the PPP hypothesis", *Econometric Theory*, 20(3), 597-625.

Pérez-Lombard, L. et al. (2008), "A review on buildings energy consumption information", *Energy and Buildings*, 40(3), 394-398.

Pesaran, M.H. & T. Yamagata (2008), "Testing Slope Homogeneity in Large Panels", *Journal of Econometrics*, (142), 50-93.

Pesaran, M.H. (2004), "General Diagnostic Tests for Cross Section Dependence in Panels", Cambridge: *University of Cambridge Working Paper*.

Pesaran, M.H. (2006), "A Simple Panel Unit Root Test in the Presence of Crosssection Dependecy", *Cambridge Working Papers in Economics*, 0346.

Pesaran, M.H. (2007), "A simple panel unit root test in the presence of cross-section dependence", *Journal of Applied Econometrics*, 22(2), 265-312.

Pesaran, M.H. et al. (1999), "Pooled Mean Group Estimation of Dynamic Heterogeneous Panels", *Journal of the American Statistical Association*, 94(446), 621-634.

Pesaran, M.H. et al. (2008), "A Bias-adjusted LM Test of Error Cross-section Independence", *Econometrics Journal*, 11, 105-127.

Pîrlogea, C. (2012), "The human development relies on energy. Panel data evidence", *Procedia Economics and Finance*, 3, 496-501.

Poumanyvong, P. & S. Kaneko (2010), "Does urbanization lead to less energy use and lower CO_2 emissions? A cross-country analysis", *Ecological Economics*, 70(2), 434-444.

Radmehr, M. & T.S. Adebayo (2022), "Does health expenditure matter for life expectancy in Mediterranean countries?", *Environmental Science and Pollution Research*, 29, 60314-60326.

Rahman, M.M. et al. (2022), "Determinants of life expectancy in most polluted countries: Exploring the effect of environmental degradation", *PLOS One*, 17(1), e0262802.

Raza, A. et al. (2025), "Nexus between CO_2 emissions, economic growth, and energy consumption with special reference to BRICS: A panel data approach", *Energy Nexus*, 20, 100556.

Ridwan, M. et al. (2026), "Heterogeneous associations of health expenditure, environmental pollution, and economic growth on life expectancy in BRICS economies", *Frontiers in Public Health*, 14, 1767163.

Rjoub, H. et al. (2021), "Sustainability of the Moderating Role of Financial Development in the Determinants of Environmental Degradation: Evidence from Turkey", *Sustainability*, 13(4), 1844.

Romer, P.M. (1990), "Endogenous Technological Change", *Journal of Political Economy*, 98(5), S71-S102.

Sadorsky, P. (2014), "The effect of urbanization on CO_2 emissions in emerging economies", *Energy Economics*, 41, 147-153.

Salim, R. et al. (2017), "Does human capital matter for energy consumption in China?", *Energy Economics*, 67, 49-59.

Sart, G. et al. (2025), "The effect of shadow economy, life expectancy, education, and income on CO_2 emissions: an analysis of BRICS countries", *Frontiers in Environmental Science*, 13, 1550389.

Sarwar, S. et al. (2020), "Revisiting the empirical relationship among the main targets of sustainable development: Growth, education, health and carbon emissions", *Sustainable Development*, 29(2), 419-440.

Satterthwaite. D. (2009), "The implications of population growth and urbanization for climate change", *International Institute for Environment and Development (IIED)*, 21(2), 545-567.

Schultz, T.W. (1961), "Investment in Human Capital", *The American Economic Review*, 51(1), 1-17.

Shafik, N. & S. Bandyopadhyay (1992), "Economic growth and environmental quality: Time series and cross-country evidence", *Policy Research Working Paper* No. 904, Washington, DC: World Bank.

Shahbaz, M. et al. (2015), "Does energy intensity contribute to CO_2 emissions? A trivariate analysis in selected African countries", *Ecological Indicators*, 50, 215-224.

Shahbaz, M. et al. (2015), "Does renewable energy consumption add in economic growth? An application of autoregressive distributed lag model in Pakistan", *Renewable and Sustainable Energy Reviews*, 44, 576-585.

Shahbaz. M. et al. (2017), "CO_2 emissions in Australia: economic and noneconomic drivers in the long-run", *Applied Economics*, 49(13), 1273-1286.

Sharma, S.S. (2011), "Determinants of carbon dioxide emissions: empirical evidence from 69 countries", *Applied Energy*, 88(1), 376-382.

Shuai, C. et al. (2017), "Identifying key impact factors on carbon emission: Evidence from panel and time-series data of 125 countries from 1990 to 2011", *Applied Energy*, 187, 310-325.

Shyamal, P. & B.N. Rabindra (2004), "Causality between energy consumption and economic growth in India: a note on conflicting results", *Energy Econ*., 26, 977-983.

Siddique, H.M.A. et al. (2020), "The impact of urbanization and energy consumption on CO_2 emissions in South Asia", *South Asian Studies*, 31(2), 745-757.

Sinha, A. & S. Sen (2016), "Atmospheric consequences of trade and human development: A case of BRIC countries", *Atmospheric Pollution Research*, 7(6), 980-989.

Solow, R.M. (1986), "On the intergenerational allocation of exhaustible resources", *The Scandinavian Journal of Economics*, 88(1), 141-149.

Somoye, O.A. & T.S. Akinwande (2023), "Can urbanization influence carbon dioxide emissions? Evidence from BRICS-T countries", *Journal of Contemporary Urban Affairs*, 7(1), 164-174.

Stern, N. (2006), *Stern Review Report on the Economics of Climate Change*, HM Treasury, London.

Su, C.W. et al. (2020), "Trade and technological innovation: the catalysts for climate change and way forward for COP21", *Journal of Environmental Management*, 269, 110774.

Tamazian, M. & B.B. Rao (2010), "Do economic, financial and institutional developments matter for environmental degradation? Evidence from transitional economies", *Energy Economics*, 32(1), 137-145.

Tamazian, M. et al. (2009), "Does higher economic and financial development lead to environmental degradation: Evidence from BRIC countries", *Energy Policy*, 37(1), 246-253.

Udeagha, M.C. & N. Ngepah (2023), "The drivers of environmental sustainability in BRICS economies: do green finance and fintech matter?", *World Development Sustainability*, 3, 100096.

Ullah, S. et al. (2020), "On the asymmetric effects of premature deindustrialization on CO_2 emissions: evidence from Pakistan", *Environmental Science and Pollution Research*, 27, 13692-13702.

Ulucak, R. & S.U.D. Khan (2020), "Relationship between energy intensity and CO_2 emissions: Does economic policy matter?", *Sustainable Development*, 28(5), 1457-1464.

UNCTAD (2025), *Fostering BRICS leadership on climate ambition amid trade and climate tensions*, <https://unctad.org/system/files/official-document/tcsditcinf2025d11_en.pdf>, 03.03.2026.

UNDP (2020), *Human Development Report 2020*, New York.

Von, P.N. (2009), "Energy consumption and income: A semiparametric panel data analysis", *Energy Economics*, 32(3), 557-563.

Wang, C.M. et al. (2019), "Bootstrap ARDL on health expenditure, CO_2 emissions and GDP growth relationship for 18 OECD countries", *Frontiers in Public Health*, 7, 324.

Wang, Q. et al. (2019), "The effects of energy prices, urbanization and economic growth on energy consumption per capita in 186 countries", *Journal of Cleaner Production*, 225, 1017-1032.

Wang, S. et al. (2014), "Urbanization, energy consumption and carbon dioxide emissions in China: A panel data analysis of China's provinces", *Applied Energy*, 136, 738-749.

Wang, Z. et al. (2012), "An empirical research on the influencing factors of regional CO_2 emissions: evidence from Beijing city, China", *Applied Energy*, 100, 277-284.

Wang, Z. et al. (2019), "Dynamic linkages among CO_2 emissions, human development, financial development and globalization: empirical evidence based on PMG long-run panel estimation", *Environmental Science and Pollution Research*, 26(36), 36248-36263.

Wang, Z. et al. (2019), "How does the new-type urbanization affect CO_2 emissions in China? An empirical analysis from the perspective of technological progress", *Energy Economics*, 80, 917-927.

Westerlund, J. (2008), "Panel Cointegration Tests of the Fisher Effect", *Journal of Applied Econometrics*, 23(2), 193-233.

Xiangyang, D. & Y. Guiqiu (2011), "China's Greenhouse Gas emissions' dynamic effects in the process of its urbanization: A perspective from shocks decomposition under long-term constraints", *Energy Procedia*, 5, 1660-1665.

Yang, L. et al. (2017), "Can China meet its 2020 economic growth and carbon emissions reduction targets?", *J. Clean. Prod*., 142, 993-1001.

Yao, Y. et al. (2020), "Human capital and CO_2 emissions in the long run", *Energy Economics*, 91, 104907.

Ye, Y. et al. (2018), "Low-carbon transportation oriented urban spatial structure: Theory, model and case study", *Sustainability*, 10(1), 19.

Yeboah, F. et al. (2024), "Wavelet-based analysis of economic growth, CO_2 emissions, and life expectancy in BRICS countries", *Journal of Cleaner Production*, 406, 136884.

York, R. (2008), "Decarbonization in former Soviet republics, 1992-2000: The ecological consequences of demodernization", *Social Problems*, 55(3), 370-390.

York, R. et al. (2003), "STIRPAT, IPAT and ImPACT: analytic tools for unpacking the driving forces of environmental impacts", *Ecological Economics*, 46(3), 351-365.

Zhan, Y. et al. (2025), "Do environmental degradation and geopolitical risk hinder life expectancy? The role of institutional quality and technological innovation", *Frontiers in Public Health*, 13, 1650912.

Zhang, C. & Y. Lin (2012), "Panel estimation for urbanization, energy consumption and CO_2 emissions: A regional analysis in China", *Energy Policy*, 49, 488-498.

Zhang, Y.J. et al. (2014), "The impact of economic growth, industrial structure and urbanization on carbon emission intensity in China", *Natural Hazards*, 73(2), 579-595.

Zheng, W. & P.P. Walsh (2019), "Economic growth, urbanization and energy consumption A provincial level analysis of China", *Energy Economics*, 80, 153-162.

Zhu, H.M. et al. (2012), "Urbanization and CO_2 emissions: A semiparametric panel data analysis", *Economics Letters*, 117(3), 848-850.

Zhu, X. et al. (2025), "The BRICS nations framework for curbing carbon emissions: Evidence from energy intensity, renewable energy, and environmental policy", *Asia & the Pacific Policy Studies*, 12(1), e70002.