BRICS JOURNAL OF ECONOMICS
DOI 10.3897/brics-econ.5.e117948
2024 Volume 5 Number 1

Tracing environmental Kuznets curves: unveiling the interplay of inequality, urbanization, GDP and emissions in BRICS nations

Biyase Mduduzi[1], Kirsten Frederich[1], Zwane Talent[1], Bila Santos[1]

1 *University of Johannesburg (South Africa)*

Corresponding author: Mduduzi Biyase (mduduzibiyase@gmail.com)

Academic editor: Sheresheva M. | Received 29 December 2023 | Accepted 19 February 2024 | Published 9 April 2024

Citation: Biyase, M., Kirsten, F., Zwane, T., Bila, S. (2024). Tracing environmental Kuznets curves: unveiling the interplay of inequality, urbanization, GDP and emissions in BRICS nations. In: Sheresheva M, Lissovolik YD (Eds) Changing the Global Monetary and Financial Architecture: The Role of BRICS-Plus. *BRICS Journal of Economics*, *5*(1), 83–104. https://doi.org/10.3897/brics-econ.5.e117948

Abstract

In light of environmental challenges, the BRICS countries have stepped to the forefront of economic progress versus environmental sustainability debate. Not only has energy consumption increased rapidly in these countries, but the economic progress and urbanization, mainly driven by intensive fossil fuel production, have also led to higher levels of income inequality. The dynamics of the interplay between economic growth, urbanization, and income inequality on the one hand and environmental sustainability on the other have yet to be fully understood in the BRICS context. This paper aims to contribute to the ongoing debate by assessing a combination of three Environmental Kuznets Curves (EKC) based on the GDPpc-emissions nexus, the income inequality- emissions nexus, and the urbanization-emissions nexus. Using the Autoregressive Distributed Lag (ADRL) and Panel Fully Modified Least Squares (FMOLS) models, we find an inverted U-shape EKC between GDP and carbon emissions, an inverted U-shaped EKC between income inequality and carbon emissions, and a U-shaped EKC between urbanization and carbon emissions. The inverted EKC between GDPpc and carbon emissions suggests that in the long run sustainable carbon reduction is possible alongside economic growth, but urbanization's U-shaped impact on emissions might hinder this. Moreover, the inverted U-shaped relationship between income inequality and carbon emissions indicates a potential long-run trade-off between reducing both inequality and carbon emissions. Factors behind this relationship may vary significantly and include institutions- and country-specific factors, yet policymakers in the BRICS countries will do well attempting to better understand the dynamics behind urbanization and inequality as it will enable them to adopt more effective holistic policies aiming to improve energy efficiency, reduce fossil fuel dependence, and build economic systems contributing to faster economic growth, lower inequality and greater environmental sustainability.

Keywords
income inequality, economic growth, urbanization, environmental sustainably, BRICS.

Аннотация
По мере усугубления экологических проблем страны БРИКС активно включились в дискуссии о соотношении экономического прогресса и экологической устойчивости. Наблюдающийся в этих странах быстрый рост потребления энергии и урбанизации, а также ускорение экономического прогресса, в первую очередь ставшие результатом интенсивного производства ископаемого топлива, в свою очередь привели к более высокому уровню неравенства доходов. Динамика взаимодействия между экономическим ростом, урбанизацией и неравенством доходов, с одной стороны, и экологической устойчивостью, с другой, пока не нашла достаточно глубокого понимания в контексте БРИКС. Данная статья призвана внести свой вклад в продолжающуюся дискуссию путем оценки комбинации трех экологических кривых Кузнеца (ЕКС), основанных на взаимосвязи ВВП с процентными выбросами и неравенством доходов и выбросов, а также связи урбанизации и выбросов. Используя модели авторегрессии с распределенным лагом (ADRL) и панельных полностью модифицированных наименьших квадратов (FMOLS), мы находим перевернутую U-образную ЕКС между ВВП и выбросами углерода, перевернутую U-образную ЕКС между неравенством доходов и выбросами углерода и U-образную зависимость ЕКС между ВВП и выбросами углерода. Используя модели авторегрессии с распределенным лагом (ADRL) и панельных полностью модифицированных наименьших квадратов (FMOLS), мы находим перевернутую U-образную ЕКС между ВВП и выбросами углерода, перевернутую U-образную ЕКС между неравенством доходов и выбросами углерода и U-образную зависимость ЕКС между ВВП и выбросами углерода. Инвертированное соотношение ЕКС между ВВП на процент и выбросами углерода предполагает, что в долгосрочной перспективе устойчивое сокращение выбросов углерода возможно наряду с экономическим ростом, но U-образное воздействие урбанизации на выбросы может этому помешать. Более того, перевернутая U-образная зависимость между неравенством доходов и выбросами углекислого газа указывает на потенциальный долгосрочный компромисс между сокращением неравенства и выбросами углекислого газа. Факторы, лежащие в основе этих отношений, могут значительно различаться и включать в себя факторы, специфичные для институтов и стран, однако политики в странах БРИКС преуспеют, пытаясь лучше понять динамику урбанизации и неравенства, поскольку это позволит им принять более эффективную целостную политику, направленную на повышение эффективности энергетики, снижение зависимости от ископаемого топлива и создание экономических систем, способствующих экономическому росту, снижению неравенства и повышению экологической устойчивости.

Ключевые слова: неравенство доходов, экономический рост, урбанизация, экологическая устойчивость, БРИКС

JEL: D63, Q50.

Introduction

In recent years, environmental challenges have escalated, with a range of pressing issues such as global warming, deforestation, loss of biodiversity, and the heightened occurrence and intensity of extreme weather events coming to the forefront. These issues, highlighted as pivotal global problems (IPCC, 2023), demand urgent action to reduce the global carbon footprint. Prominent among these is the Paris Agreement, a legally binding international treaty on climate change, that aims to keep global average temperatures below an excess of 2°C pre-industrial levels and to pursue the target of keeping temperatures at 1.5°C above the pre-industrial levels. However, to achieve these targets, carbon emissions need to be halved by 2030 (UN, 2023). This is particularly challenging for the nations whose industrial growth and urbanization have mainly been led by fossil fuel production and accompanied by increased amounts of carbon emissions (Hasan et al., 2023)

For emerging economies, particularly those in the BRICS group (China, India, Brazil, Russia and South Africa), economic growth and urbanization have been closely tied to fossil fuel use. The rapid economic expansion of some BRICS countries comes at the cost of higher carbon emissions. BRICS economies account for three of the world's top five carbon emitters and have surpassed OECD countries in terms of carbon dioxide emissions (Zhu et al., 2018) while accounting for over 46% of global emissions, with a dramatic increase from 1995 to 2020 (Hasan et al., 2023). At the same time, inequality in South Africa remains one of the highest globally (World Bank, 2023); in China and India it has increased (Wolde-Rufael & Idowu, 2017).

Understanding the balance and dynamics of economic growth, inequality urbanization and carbon emissions in BRICS countries is crucial and this is where the Environmental Kuznets Curve (EKC) provide valuable insight. The EKC suggests that the quality of the environment initially worsens with economic development but begins to improve once a certain income per capita level is exceeded. The EKC has been increasingly exploited to find out how economic growth impacts emissions (Liobikienė, 2020; Al-Mulali and Ozturk, 2016; Yang et al., 2021; Pata and Caglar, 2021). Zhu et al. (2018) examined the impact of GDPpc, urbanization and inequality on emissions among the BRICS nations. Their findings support the inverted U-shaped EKC between GDP and emissions. This pattern indicates that economic growth initially increases carbon emissions. However, upon reaching a turning point, further economic expansion is coupled with a decline in carbon emissions. In their analysis, Zhu and others also control for income inequality and urbanization, and their empirical findings of an inverted U-shape are in line with other studies, that support the hypothesis within a BRICS context (Ummalla and Goyari, 2020; Hasan et al., 2023).

Our study aims to delve deeper into the EKC phenomena within the BRICS countries, particularly focusing on the interplay between three EKC patterns: GDPpc, income inequality and urbanization. We hypothesize that each of these EKCs exhibits distinct relationships with emissions and has heterogenous patterns. This research makes several contributions to the field of environmental economics: firstly, it provides a comprehensive analysis of the EKC phenomenon by simultaneously assessing three critical variables, GDPpc, urbanization and inequality and the impact on emissions. Secondly, this study sheds new light on EKCs concerning income inequality and carbon emission in BRICS countries. Given the increasing inequality in some of these nations, the research offers valuable insights into the long-run interplay between economic disparities and environmental sustainability. This is especially significant in the BRICS context, where such dynamics have been less understood. Thirdly, the findings of the study may prove useful for formulating targeted environmental policies and economic strategies that can help these nations achieve sustainable growth without compromising their environmental commitments. Overall, the study should contribute to the existing literature by providing empirical evidence of these relationships, offering new insights into the distinct EKC patterns in a BRICS context.

The rest of the manuscript is structured as follows: Section 2 provides a detailed description of the literature for this study; Section 3 outlines the methodology used; Section 4 presents the descriptive and empirical analysis of the data. Finally, section 5 concludes the findings of the study and presents some policy recommendations.

Literature review

The causal association between income inequality and environmental quality through greenhouse gas emissions has been contested in empirical studies (see for example, Ravallion et al., 2000; Heerink et al., 2001; Borghesi, 2006; Guo, 2014; Grunewald et al., 2017; Ma et al., 2019; Balsalobre-Lorente et al., 2021). The basis for the assessment of the position that income inequality plays in facilitating the relationship between economic progress and environmental quality is the notable environment Kuznets curve (EKC) proposition. The EKC proposition assumes an inverted U-shaped linkage between economic progress and environmental degradation (Hao et al. 2016; Knight et al., 2017). This means that environmental degradation increases as per capita income rises at the first phase of economic expansion but falls after a certain threshold of per capita income is exceeded (see for example, Golley & Meng, 2012; Wolde-Rufael & Idowu, 2017).

Although recent empirical work has shown that it is not only income that plays a role here, its distribution is also a fundamental element that determines the level of aggregate emissions and so the quality of the environment (Jorgenson et al., 2017; Kashwan, 2017; Kasuga & Takaya, 2017; Nyangena et al., 2019). Accordingly, there is an increasing interest in exploring the function of national per capita income along with its distribution on per capita carbon emissions and its implication for the global environment (Wolde-Rufael & Idowu, 2017; Kashwan, 2017).

There are various approaches through which income distribution might explicitly impact per capita carbon dioxide emissions. In his study, Boyce (1994) advocates for a political economy approach (PEA) to describe theoretically the negative effect of income inequality on environmental pollution. The author claims that the most affluent sections of society often have a drive for increased environmental degradation as they own polluting companies that increase carbon-intensive consumption of industrial goods and services (Wolde-Rufael & Idowu, 2017). As per Boyce's (1994) political economy model, these sections have bargaining influence to amend policy environments so that they can bypass expensive environmental protection. In particular, using a model of power-weighted social decision rule, Boyce (1994) reveals that the affluent sections of society apply their economic and political negotiating power to influence policymakers' efforts to promote environmental protection measures (Boyce, 1994). Applying their economic and political influence, the richest classes derive the pay-off from their polluting activity (Boyce, 1994; Boyce et al., 1999), while the poverty-stricken layers of society pay the price of environmental pollution (Boyce et al., 1999; Ciplet et al., 2015).

It is interesting to note that Scruggs (1998) disputes the theory propounded by Boyce (1994). In this study, Scruggs (1998) argues his point by providing an analogy that if the environment was a normal good, an increase in per capita income should be linked to the same level of preference for environmental pollution. Alternatively, if the environment was a superior good, then an increase in income should be linked to a lower level of preference for environmental degradation (Scruggs, 1998). This line of thinking is that the richest class favours a clean environment and consequently promotes environmental regulations as income increases (Scruggs, 1998).

The alternative purported theory to describe the association between income inequality and carbon emissions is the marginal propensity to emit (MPE) (see for example, Ravallion et al., 2000; Berthe & Elie, 2015). Under the Keynesian model of marginal propensity to consume (MPC), the MPC for those at the bottom of the pyramid is often higher than the MPC for those at a higher level of the same pyramid (Grunewald et al., 2017; Jorgenson et al., 2017). This means that equality through an increase in the income of those at the bottom of the pyramid to catch up with those at the top reveals a higher marginal propensity to consume energy, and so a higher marginal propensity to emit (Liobikienė & Rimkuvienė, 2020; Hailemariam et al., 2020). Consequently, higher equality within society often impairs the environment, which implies the existence of a channel that allows for a negative association between income inequality and carbon emissions (Hailemariam et al., 2020; Hundie, 2021).

Several empirical works have explored the impact of national income and its distribution on per capita carbon emissions; other studies have incorporated the effect of urbanization into the equation (Parikh & Shukla, 1995; Ravallion et al., 2000; Grunewald et al., 2017; Kasuga & Takaya, 2017; Xu et al., 2018; Nyangena et al., 2019). Surprisingly, the empirical results of this research are at best inconclusive. Some studies have documented a positive association between the variables (Parikh & Shukla, 1995; Nyangena et al., 2019; Xu et al., 2018; Wang et al., 2022); another strand of literature has revealed a mitigating impact of these variables on emissions (Ravallion et al., 2000; Heerink et al., 2001; Borghesi, 2006; Guo, 2014; Grunewald et al., 2017; Ma et al., 2019; Balsalobre-Lorente et al., 2021). Other studies, however, have found no significant relationship between these important variables (Scruggs, 1998; Wolde-Rufaela & Idowub, 2017).

The previous research recognizes the critical role of urbanization, inequality and GDP growth in increasing emissions. For example, a study by Parikh and Shukla (1995) applied data covering 83 developed and emerging nations for the year 1986 to analyse the impact of urbanization on energy use and toxic emissions. The authors reported that urbanization had a positive and statistically significant effect on emissions. York et al. (2003), Nyangena et al. (2019) and Wang et al. (2022) are likewise among the notable studies that present evidence in favour of the positive relationship between urbanisation and environmental quality. In their study, York et al. (2003) used a cross-section of data from 137 countries to examine the association between urbanization and carbon emissions. Consistent with the work of Parikh and Shukla (1995), York et al. (2003) also reported a positive association between urbanization and emissions. Reaching a similar conclusion, Nyangena et al. (2019) examined the contribution of urbanization on carbon emissions in the East African region. Nyangena et al. (2019) implemented panel data for selected nations in the region and tested the EKC hypothesis. The author employed parametric and semi-parametric fixed-effects techniques and results comparison. The findings strikingly showed that urbanization and economic growth were responsible for continued environmental deterioration in the region (Nyangena et al., 2019).

Among recent contributions, Wang et al. (2022) used panel data from 134 nations covering the period between 1996 and 2015 and applied the threshold regression model to analyze the effect of urbanization on the coupling of economic growth and environmental quality. Wang et al. (2022) found that urbanization reinforces the positive association between the economy development and carbon emissions and ecological footprint. The authors reported that the positive impact of economic growth on the ecological footprint was stronger than that of carbon emissions. Further results showed that trade openness and natural resource rents increase environmental pressure (Wang et al., 2022). In their recent empirical work, Rahman and Vu (2020) explore the effect of urbanization on emissions applying time series data and also compare the results for Australia and Canada. The comparison reveals that in the long run urbanization increases emissions in Canada but decreases emissions in Australia (Rahman & Vu, 2020). The authors conclude that urbanization affects emissions in a mixed way and the evidence is rather inconclusive (Rahman & Vu, 2020).

As concerns inequality, in their seminal paper Torras and Boyce (1998) explored the effect of three power inequality indicators – income inequality proxied by the Gini index, literacy, and political rights – on emissions in 42 nations. Torras and Boyce (1998) found that power inequality raised environmental pollution with a greater impact in low-income nations. Arriving at the same conclusion, Gawande et al. (2001) applied the Gini index as a measure of income inequality and reported that a broadening gap in income distribution worsens environmental quality.

In their paper, Hailemariam et al (2019) explored the economic growth- emissions using data on top income inequality measured by the share of pretax income earned by the richest 10% of the inhabitants of the OECD nations and Gini coefficients, as these two measures account for diverse structures of the income distribution (Hailemariam et al, 2019). The authors used panel data models and found a positive association between top-income inequality and emissions (Hailemariam et al., 2019). Likewise, Grunewald et al. (2017) used group fixed effects model to explore the effect of income inequality on emissions. The authors reported that the correlation between the two factors depends on the level of income (Grunewald et al., 2017). Specifically, they found a negative and statistically significant relationship between income inequality and emissions in low- and middle-income countries and a positive relationship between upper-middle-income and high-income countries (Grunewald et al., 2017).

Recent empirical studies suggest that there is a negative causal association between urbanization, inequality, GDP growth and carbon emission. Several empirical works, such as Ravallion et al. (2000), Heerink et al. (2001), Borghesi (2006), Guo (2014), Grunewald et al. (2017), Ma et al., (2019), Balsalobre-Lorente et al. (2021), show a negative association between these variables, thus suggesting, for example, the presence of a trade-off between promoting equality and improving environmental quality. For example, Ravallion et al. (2000) applied pooled OLS model together with panel data for 42 nations using data covering the period 1975 to 992. Ravallion et al. (2000) showed a negative association between income inequality and aggregate carbon emissions in the nations under investigation. The authors concluded that controlling climate change and promoting equity can entail certain trade-offs between these two aims (Ravallion et al., 2000).

Subsequent empirical work, such as Heerink et al. (2001), found that an increase in income inequality results in a significant increase in emissions. When the correlation between environmental damage and income is concave (for instance, mimicking the EKC), income inequality is negatively linked to total environmental degradation (Heerink et al., 2001). Similar to the results obtained by Heerink et al. (2001), Ravallion et al. (2000) also showed that increased inequality both between and within nations is linked with decreased emissions at given average incomes. In this study, the author also confirmed that economic growth largely comes with increased emissions (Ravallion et al., 2000). The authors concluded that their findings revealed a trade-off that occurs between climate control, on the one hand, and both social equity and economic growth on the other (Ravallion et al., 2000).

There are studies, however, that have found no significant relationship between these variables. For instance, Scruggs (1998) queried the standpoints of Boyce (1994) and claimed that there was no significant causal association between income distribution and environmental quality. Scruggs' (1998) argument was based on the results obtained through testing the PEA for different country categories. The author reported that the impact of income distribution had changed according to the environmental factors and no clear evidence has been obtained (Scruggs, 1998). In line with the findings of Scruggs (1998), Magnani (2000) investigated the phenomena within the OECD countries using data covering the period from 1980 to 1991. The study failed to report a clear association between the Gini coefficient and research and development expenditures for environmental protection (Magnani, 2000). Similar to Magnani (2000), Wolde-Rufaela and Idowub (2017) used a bounds-test technique to co-integrate and reported a long-run but statistically insignificant association between income distribution and emissions in both China and India. The authors concluded that with regard to the linkage between income inequality and emissions, the results are varied and inconclusive.

Methodology

Data

While the relationship and non-linearity effect of per capita GDP has been explored quite extensively under the EKC perspective in the environmental field (Voumik et al., 2023; Hasan et al, 2023; Pata & Caglar, 2020), the non-linearity between emissions and inequality & urbanization has not been fully investigated and so we endeavor to make some effort in analyzing this nexus. To do so, the study uses data covering a panel of BRICS countries over the period of 31 years, from 1990 to 2020. Most of the data are from the World Development Indicators (e.g emissions, gross domestic product, urbanization, services, agriculture and manufacturing, all value added) and inequality measure was sourced from the Standardized World Income Inequality Database (SWIID).

Model specification and estimation technique

To fulfil the objective, the study builds from the EKC, as previously used by Avenyo and Tregenna (2021) and Khan et al (2020), presenting the formal model as follows:

$$CO_2 = f(IE, GDP, EU, URBN, AGRVA, MANVA, SERVA), \tag{1}$$

Where

the acronyms denote the following: CO_2 (carbon dioxide) *IE* (income inequality), *GDP* (gross domestic product per capita), *EU* (energy use), *URBN* (urbanization), *AGRVA* (agricultural value added), *MANVA* (manufacturing value added) and *SERVA* (services value added). The CO_2 is measured in kilotons, *IE* measured by the gini coefficient, *GDP* measured in 2015 constant terms to ensure that it is introduced into the equation in real terms, *EU* measured in kilograms of oil equivalent (kgoe) per capita, *URBN* measured as a percentage of the total population, *AGRVA*, *MANVA* and *SERVA* are measured as a percentage of GDP.

Employing the natural logarithm transformation to improve the interpretability of the results, we assemble the linear model as follows:

$$LCO_{2it} = \beta_0 + \beta_1 LIE_{it} + \beta_2 LIE_{it}^2 + \beta_3 LGDPpc_{it} + \beta_4 GDPpc_{it}^2 + \\ + \beta_5 LEU_{it} + \beta_6 LUBRN_{it} + \beta_7 LURBN_{it}^2 + \beta_8 LSERVA_{it} + \beta_9 LAGRVA_{it} + \\ + \beta_{10} LMANVA_{it} + \alpha_i + e_{it}, \quad (2)$$

Moreover, LIE_{it}^2, $GDPpc_{it}^2$ and $LURBN_{it}^2$ are introduced into the equation to account for the non-linearity in the income inequality, *GDPpc* and urbanization nexus.

Where β_1, β_2, β_3, β_4, β_5, β_6, β_7, β_8, β_9, β_{10} are the coefficients of the independent variables that shall be estimated, *it* is the intercept, and α_i, e_{it} are country specific effect and error terms. In order to explore the long-run and short-run relationship between these variables, equation (1) is restated as the ARDL equation below:

$$\Delta LCO_{2it} = \alpha_0 + \sum_{i=1}^{n} \varnothing_1 \Delta CO_{2t-i} + \sum_{i=1}^{n} \varnothing_2 \Delta LIE_{it} + \sum_{i=1}^{n} \varnothing_3 \Delta LIE_{it}^2 + \\ + \sum_{i=1}^{n} \varnothing_4 \Delta LGDPpc_{it} + \sum_{i=1}^{n} \varnothing_5 \Delta LGDPpc_{it}^2 + \sum_{i=1}^{n} \varnothing_6 \Delta LEU_{it} + \\ + \sum_{i=1}^{n} \varnothing_7 \Delta LURBN_{it} + \sum_{i=1}^{n} \varnothing_8 \Delta LURBN_{it}^2 + \sum_{i=1}^{n} \varnothing_9 \Delta LSERVA_{it} + \\ + \sum_{i=1}^{n} \varnothing_{10} \Delta LAGRVA_{it} + \sum_{i=1}^{n} \varnothing_{11} \Delta LMANVA_{it} + \beta_1 LCO_{2it} + \beta_2 LIE_{it} + \\ + \beta_3 LIE_{it}^2 + \beta_4 LGDPpc_{it} + \beta_5 LGDPpc_{it}^2 + \beta_6 LEU_{it} + \beta_7 \Delta LURBN_{it} + \\ + \beta_8 \Delta LURBN_{it}^2 + \beta_9 \Delta LSERVA_{it} \beta_{10} \Delta LAGRVA_{it} + \beta_{11} \Delta LMANVA_{it} + u_{it}. \quad (3)$$

Where α_0 signifies the intercept, Δ is the first difference operator, $\varnothing_1$, $\varnothing_2$, $\varnothing_3$, $\varnothing_4$, $\varnothing_5$, $\varnothing_i$, $\varnothing_6$, $\varnothing_7$, $\varnothing_8$, $\varnothing_i$, $\varnothing_9$, $\varnothing_{10}$ and $\varnothing_{11}$, shows the short-run estimated coefficients of our variables. The long-run estimated coefficient are then deduced from $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6, \beta_7, \beta_8, \beta_9, \beta_{10}, \beta_{11}$. Once we ascertain the presence of the long-run association between variables, then we estimate the error correction model (ECM) as shown below:

$$\Delta LCO_{2it} = \alpha_0 + \sum_{i=1}^{n} \varnothing_1 \Delta CO_{2t-i} + \sum_{i=1}^{n} \varnothing_2 \Delta LIE_{it} + \sum_{i=1}^{n} \varnothing_3 \Delta LIE_{it}^2 + \\ + \sum_{i=1}^{n} \varnothing_4 \Delta LGDPpc_{it} + \sum_{i=1}^{n} \varnothing_5 \Delta LGDPpc_{it}^2 + \sum_{i=1}^{n} \varnothing_6 \Delta LEU_{it} + \\ + \sum_{i=1}^{n} \varnothing_7 \Delta LURBN_{it} + \sum_{i=1}^{n} \varnothing_8 \Delta LURBN_{it}^2 + \sum_{i=1}^{n} \varnothing_9 \Delta LSERVA_{it} + \\ + \sum_{i=1}^{n} \varnothing_{10} \Delta LAGRVA_{it} + \sum_{i=1}^{n} \varnothing_{11} \Delta LMANVA_{it} \quad + \rho_1 ECM_{t-1} \quad (4)$$

Equation (4) is similar to equation (3) except for the Δ which represent the coefficient for the speed of adjustment to equilibrium. Due to the fact that different specification estimator can somehow be sensitive, we further use the Full Modified Ordinary Least Square for robustness check.

Empirical Analysis

Table 1 demonstrates the descriptive statistics of the variables used in this study. Reporting on the variables of interest, the statistics show that the mean value of logged emissions is 1.16796, the maximum value is 2.475, and the minimum value is -0.4347 with a standard deviation, which is 0.9307. The mean value for LIE is 3.8422, a maximum value of 4.1495, a minimum value of 3.1905 and a standard deviation of 0.208. The mean value of LGDPPC is 8.3136, and the maximum and minimum are 9.2455 and 6.2708 respectively with a standard deviation of 0.9088. The mean value of LURBN is 3.9926, with a maximum of 4.4667, a minimum value of 3.2405, and a standard deviation of 0.4040.

Table 1. Descriptive stats

	LCO2	LIE	LGDPPC	LEU	LURBN	LAGRVAR	LMANVA	LSERVAR
Mean	1.167961	3.842233	8.313581	2.994025	3.992577	25.06955	2.815272	27.16802
Median	0.870993	3.829722	8.704638	3.492551	4.078765	24.86812	2.746723	27.26665
Maximum	2.475273	4.149464	9.245531	3.969348	4.466747	27.72248	3.479772	29.67941
Minimum	-0.434712	3.190476	6.270796	1.156881	3.240520	22.07652	2.335294	25.33718
Std. Dev.	0.930702	0.208024	0.908828	0.945841	0.404001	1.613991	0.314657	1.078579
Skewness	-0.052304	-0.416868	-1.041112	-0.782898	-0.605522	-0.258362	0.673869	0.280718
Kurtosis	1.528344	3.096453	2.626329	2.306465	1.923973	2.185258	2.613835	2.789717
Jarque-Bera	10.88358	3.522101	22.37643	14.66355	13.12230	4.654049	9.827610	1.797143
Probability	0.004332	0.171864	0.000014	0.000654	0.001414	0.097586	0.007344	0.407151
Observations	120	120	120	120	120	120	120	120

Source: Authors' computations

The variables of interest in this study focus on uncovering the relationship between carbon emissions, GDPpc, income inequality and urbanization in BRICS countries. Figures 1 to 3 depict the evolution of these variables over 1990-2020. The analysis begins with Figure 1 and 2, and shows the evolution of emissions and GDPpc. Although GDPpc appears to fluctuate a lot as compared to emissions in the BRICS nations, by and large there appears to be a positive association between the two variables. This trend is not surprising, but rather consistent with the theory that says an increase in economic growth tends to stimulate industrial activity and energy consumption, which in turn leads to higher emissions.

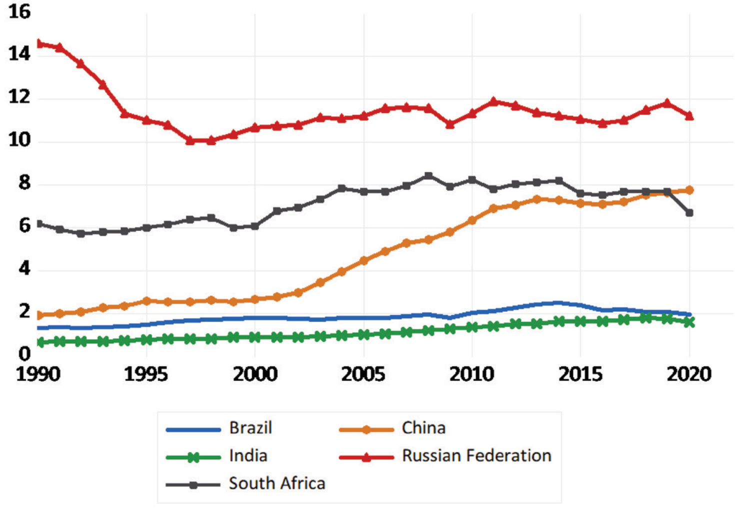

Figure 1. Trends in C02 emissions in Brics nation. *Source*: Authors' computations derived from the WDI

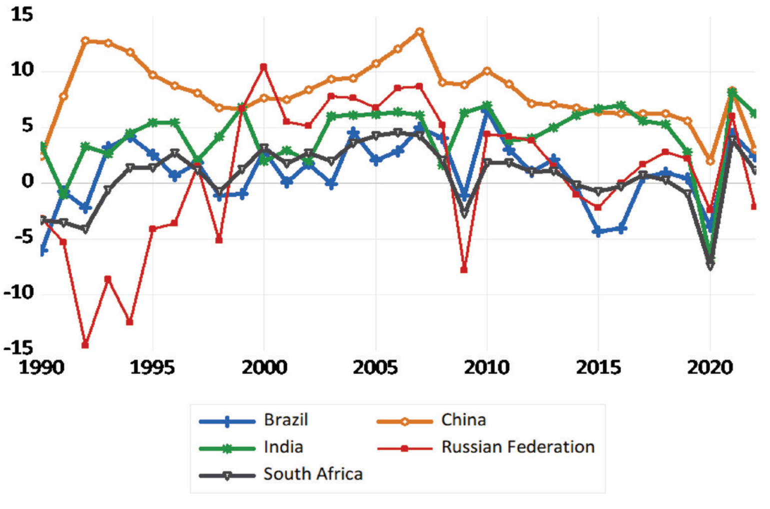

Figure 2. Trends in GDP per capita growth in Brics nations. *Source*: Authors' computations derived from the WDI

The next focus is on the interplay between income inequality and emissions in Figures 2 and 3. For China and South Africa, a concurrent upward trend is observed between income inequality and emissions. In Brazil, India, and Russia, however, this relationship is less clear. Notably, India and Brazil exhibit a divergent trend between income inequality and emissions. Finally, figures 1 and 4 show the relationship between urbanization and emissions. A general trend emerges showing a parallel increase in both urbanization and missions across all BRICS countries, except for Russia.

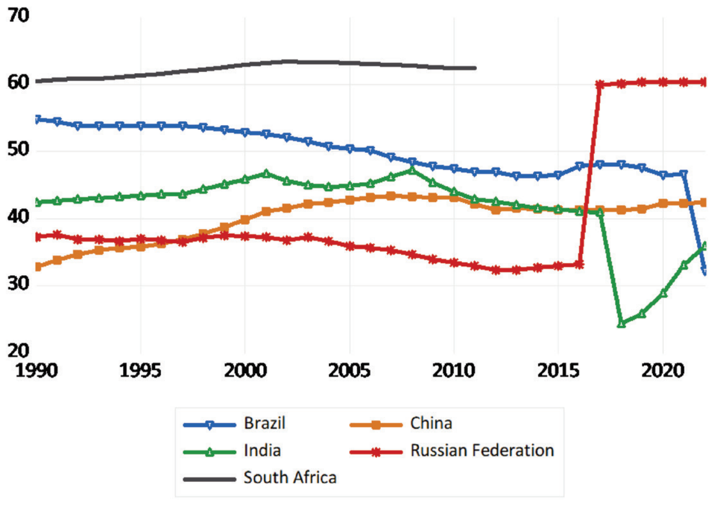

Figure 3. Trends in inequality in Brics nations. *Source*: Authors' computations derived from the SWIID

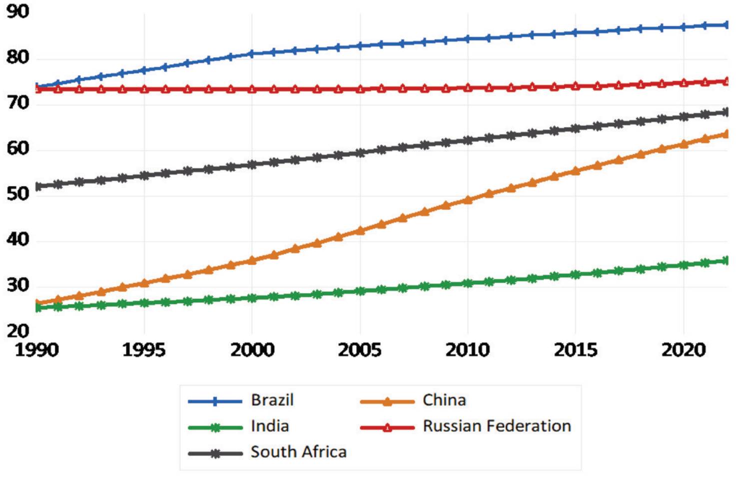

Figure 4. Trends in urbanization in Brics nations. *Source*: Authors' computations derived from the WDI

Unit root test

The next step involves checking the stationarity levels of the variables. Table 2 below shows the results for four types of panel unit root tests: the Levin, Lin & Chu t*; Im, Pesaran and Shin W-stat; ADF-Fisher Chi-square and PP-Fisher Chi-square, which are used to determine if the series contains a unit root or not. The estimates reported in Table 2 show a combination of I(0) and I(1), meaning some of the series are stationary at level, although the majority of them come to be stationary only after the first difference.

For example, across the board, LAGRVAR, LMANVA and LSERVAR are nonstationary at level but only become stationary after the first difference. Other variables vary depending on the method used.

Table 2. Panel unit root estimates

Variables	Levin, Lin & Chu t*	Im, Pesaran and Shin W-stat	ADF - Fisher Chi-square	PP - Fisher Chi-square
		At level		
LCO2	-1.67758	-0.90828	15.4086	11.6805
	0.0467	0.1819	0.1179	0.307
LIE	-0.98971	1.10143	7.2595	11.201
	0.1612	0.8646	0.7007	0.3421
LGDPPC	-2.76163	0.74998	7.33142	6.12064
	0.0029	0.7734	0.6938	0.805
LEU	-1.62047	-0.29859	8.22229	8.23377
	0.0526	0.3826	0.6071	0.606
LURBN	-1.14935	2.45741	5.10244	57.3877
	0.1252	0.993	0.8842	0.0000
LAGRVAR	0.25994	3.24924	1.65914	1.83709
	0.6025	0.9994	0.9983	0.9974
LMANVA	-0.96007	0.69085	5.52638	5.53209
	0.1685	0.7552	0.8534	0.8529
LSERVAR	-3.26707	0.55771	6.90884	6.60551
	0.0005	0.7115	0.734	0.7621
		First difference		
LCO2	-0.5281	-2.10034	20.7494	
	0.2987	0.0178	0.0229	
LIE	-0.22653	-1.25229	23.4824	44.7113
	0.4104	0.1052	0.0091	0.0000
LGDPPC	-3.35888	-3.75591	34.7426	53.3553
	0.0004	0.0001	0.0001	0.0000
LEU	0.92865	-1.46923	23.3907	49.181
	0.8235	0.0709	0.0094	0.0000
LURBN	-1.239		14.4334	20.118
	0.1077		0.1541	0.0282
LAGRVAR	-10.9098	-10.8644	80.3604	136.242
	0.0000	0.0000	0.0000	0.0000
LMANVA	-4.31095	-4.67288	42.04	59.6569
	0.0000	0.0000	0.0000	0.0000
LSERVAR	-2.61077	-2.57699	25.6582	45.3358
	0.0045	0.005	0.0042	0.0000

Utilizing the unit root findings, in table 3 we now present the test results of Pedroni cointegration for the GDPpc-; inequality- emissions and urbanization- emissions nexus. Predictably the majority of the statistics (such as the Panel PP-Statistic, Panel ADF-Statistic, Group PP-Statistic and Group ADF-Statistic) fail to accept the null hypothesis of no cointegration. In other words, the Pedroni cointegration results confirm that the variables have a long-run relationship.

Table 3. Pedroni Cointegration Test Results

Within-dimension				
			Weighted	
	Statistic	Prob.	Statistic	Prob.
Panel v-Statistic	-0.880466	0.8107	-3.122421	0.9991
Panel rho-Statistic	3.690677	0.9999	3.995235	1.0000
Panel PP-Statistic	-5.312261	**0.0000*** **	**-5.306100**	**0.0000*** **
Panel ADF-Statistic	-1.785919	**0.0371*** **	**-1.958545**	**0.0251*** **
Between-dimension				
	Statistic	Prob.		
Group rho-Statistic	4.617716	1.0000		
Group PP-Statistic	-8.756492	**0.0000*** **		
Group ADF-Statistic	-2.202279	**0.0138*** **		

ARDL estimates

Since we confirm the long-run cointegration between emissions and the variables of interest, we now perform an PADRL model to assess the long-run results of the study. The results of the PADRL model in Table 4 demonstrate both the short-run and long-run effects of covariates on emissions. In the long run, the positive coefficients for LIE, and LGDPPC suggest a positive long-term relationship with D(L), while the negative coefficients of LEU, LURBN, LSERVAR, and LMANVAR indicate a negative relationship with CO_2 emissions. Specifically, the estimated coefficients are 2.927244; -0.383767; 1.183061; -0.005808; -0.624737; -5.392398; 0.518098; -0.1417971; 0.201318; 0.052382 for LIE; LIE^2; LGDPPC; LGDPpc^2; LEU; LURBN; LURBN^2; LSERVAR; LAGRVAR and LMANVAR respectively. This suggests that in the long-run the degree of responsiveness of the dependent variable (CO_2) to income inequality is 2.927244 -0.383767; the long-run responsiveness of the CO_2 to GDPpc is 1.183061 -0.005808; the a 1% increase in energy use brings about 0.624737% reduction in CO_2 emissions; in the long-run, the degree of responsiveness in the long-run of the CO_2 to urbanization is -5.392398 0.518098. A 1% increase in LSERVAR reduces emissions by approximately 0.141797%; a 1% increase in LAGRVAR increases emissions by 0.201318% and a 1% increase in LAGMANVAR reduces emissions by 0.052382%.

This study's main contribution is testing the dynamics of three different Environmental Kuznets Curves (EKC): GDP and CO_2 emissions, inequality and CO_2

emissions and urbanization and CO_2 emissions. The results support the inverted U-shape EKC for inequality and GDP, where both LIE and LGDPpc are positively and significantly related to CO_2 emission, while their squared terms ((LIE^2 $LGDPpc^2$) are negatively related. Initially, an increase in GDP and income inequality leads to higher levels of CO_2 emissions; in the long run, however, this relationship reverses, and higher levels of GDP and income inequality lead to lower CO_2 emissions. For GDP and CO_2 emissions, BRICS countries would initially experience higher levels of CO_2 emissions, but economic development will eventually lead to lower CO_2 emissions once GDP surpasses a certain threshold. The results of an inverted U-shape EKC within BRICS countries are consistent with other studies like Zhu et al., (2018), Fang et al (2022), Sinha et al., (2019) and Voumik et al., (2023). While our analysis reveals a positive relationship between GDP per capita and CO_2 emissions, the insignificance of the squared GDP per capita term introduces uncertainties regarding the presumed beneficial impact of economic growth on carbon emissions reduction, as suggested by the Environmental Kuznets Curve (EKC). This finding prompts a reevaluation of the EKC's applicability, particularly in the context of BRICS nations. These countries exhibit a diverse array of economic, environmental, and policy landscapes that may not conform to the traditional EKC hypothesis. The complexity and variability inherent in the BRICS economies suggest that the relationship between economic growth and environmental degradation cannot be succinctly captured by a simple inverted-U curve. This observation underscores the necessity for a more nuanced analysis that considers country-specific factors and the multifaceted nature of economic development and environmental impact.

The relationship with income inequality is less clear. Given the high level of inequality in these countries, reducing both inequality and their carbon footprint is crucial. However, the inequality- relationship shows an inverted U-shape EKC, where initially income inequality and CO_2 emissions have a positive and significant relationship, suggesting the potential for simultaneous reduction. However, over time the relationship becomes negative and higher inequality is associated with a lower carbon footprint. This suggests a potential trade-off between inequality and carbon reductions in the current development path of BRICS nations. The findings of an inverse relationship between income inequality and environmental degradation are not uncommon and some have found it to be linked to middle-income countries (Grunewald et al., 2017) and country-specific conditions (Ota, 2017), while others have highlighted the role of institutions (Yang et al., 2021). All these factors are vital in the BRICS context and further analysis needs to be undertaken to understand the future role of inequality and carbon reductions in these countries.

In contrast to GDPpc and income inequality, we find that urbanization has a U-shaped EKC, where the urbanization-CO_2 emission nexus starts with an initial negative relationship that becomes positive after a certain threshold. This indicates that increased levels of urbanization in BRICS countries initially lead to lower levels of CO_2 emissions, but in the long run there will be a trade-off between further urbanization and CO_2 emissions. These results are in line with Pianoing and Kaneko (2010) and Shahbaz et al., (2016), who also found that at first urbanization reduces CO_2 emissions, but after a threshold level, it increases CO_2 emissions. Since urbanization is a natural process of economic development, BRICS policymakers could focus on sustainable urban planning, renewable energy technology and innovations to reduce the harmful impact of the current urbanization trajectory.

The negative effect of LSERVAR and LMANVA on emissions could be explained by technological advancements in manufacturing that reduce carbon footprints or by the shift of economic structures toward service-orientated sectors that produce markedly less carbon emissions (Okamoto, 2013) compared to agriculture, which had a positive effect on CO_2 emissions.

Table 4. Autoregressive Distributed Lag regression results

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
		Long Run Equation		
LIE	2.927244	1.037676	2.820961	0.0068
	-0.383767	0.136866	-2.803958	0.0072
LGDPPC	1.183061	0.591942	1.998611	0.0511
	-0.005808	0.032126	-0.180771	0.8573
LEU	-0.624737	0.019281	-32.40173	0.0000
LURBN	-5.392398	1.422524	-3.790725	0.0004
	0.518098	0.167952	3.084797	0.0033
LSERVAR	-0.141797	0.095791	-1.480283	0.1451
LAGRVAR	0.201318	0.050426	3.992313	0.0002
LMANVAR	-0.052382	0.023306	-2.247572	0.0290
		Short Run Equation		
COINTEQ01	-0.905449	0.249165	-3.633936	0.0007
D(LCO2(-1))	-0.051051	0.327283	-0.155985	0.8767
D(LIE)	-196.9917	239.6183	-0.822106	0.4149
D()	23.68570	29.29755	0.808453	0.4227
D(LGDPPC)	56.34348	38.60980	1.459305	0.1507
D()	-3.163045	2.138215	-1.479293	0.1453
D(LEU)	0.078170	0.258001	0.302983	0.7632
D(LURBN)	-2531.321	2499.045	-1.012915	0.3160
D()	292.6175	288.0523	1.015848	0.3146
D(LSERVAR)	0.236631	0.555148	0.426249	0.6718
D(LAGRVAR)	-0.390277	0.481624	-0.810335	0.4216
D(LMANVAR)	0.113816	0.092361	1.232293	0.2236
Root MSE	0.015314	Mean dependent var		0.019657
S.D. dependent var	0.043268	S.E. of regression		0.023724
Akaike info criterion	-4.591847	Sum squared resid		0.028142
Schwarz criterion	-2.965810	Log likelihood		345.5108
Hannan-Quinn critter.	-3.931506			

* Note: p-values and any subsequent tests do not account for the model selection.

Table 5. Panel Fully Modified Least Squares (FMOLS)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LIE	2.177887	0.052296	41.64546	0.0000
	-0.337711	0.053209	-6.346830	0.0000
LGDPPC	5.398281	0.077035	70.07602	0.0000
	-0.265393	0.043559	-6.092692	0.0000
LEU	-0.289742	0.068172	-4.250157	0.0000
LURBN	-14.86930	0.016053	-926.2708	0.0000
	1.916970	0.004907	390.6931	0.0000
LSERVAR	-0.436541	0.044440	-9.823173	0.0000
LAGRVAR	0.108272	0.041084	2.635346	0.0097
LMANVA	-0.082952	0.007529	-11.01834	0.0000
R-squared	0.996464	Mean dependent var		1.171670
Adjusted R-squared	0.995969	S.D. dependent var		0.926083
S.E. of regression	0.058800	Sum squared resid		0.345744
Long-run variance	0.000593			

Table 4 presents the findings from the Fully Modified Ordinary Least Squares (FMOLS) model, which is aligned with the results of the PADRL regression analysis. This consistency between the two distinct analytical approaches reinforces the robustness of our outcomes indicating that GDPpc and income inequality have an inverted U-shaped relationship with carbon emissions and urbanization has a U-shaped relationship with carbon emissions. Overall, these EKC patterns suggest that sustainable long-run carbon reductions are possible alongside the inverted GDP- emissions EKC. However, the U-shaped EKC for urbanization could offset the long-term positive impact of economic growth on CO_2 emissions. Policymakers should consider the role urbanization might have in the future when limiting the BRICS countries' carbon reductions. Moreover, the relationship between income inequality and CO_2 emissions is still complex: the initial stages of development suggest that BRICS countries could simultaneously reduce them both, but the long-run pattern involve a possible trade-off between inequality and environmental sustainability. Factors like institutions and country-specific inequality dynamics are certainly vital for addressing these challenges; from a policy perspective, however, the BRICS countries need to implement policies that address these challenges holistically. This could include measures to improve energy efficiency, reduction in fossil fuel-led production, and transition to economic systems that can reduce inequality while fostering sustainable development.

Conclusion

In this paper, our main purpose is to investigate the impact of GDPpc, income inequality, and urbanization through separate Environmental Kuznets Curves. The PARDL and FMOLS regression results both suggest that GDPpc follows an inverted U-shaped EKC, urbanization a U-shaped EKC, and income inequality an inverted U-shape. These findings highlight the importance of understanding long-run environmental sustainability among BRICS nations. For example, the inverted U-shape between GDPpc and carbon emissions suggest a future threshold turning point for BRICS nations. This turning point could see greater public demand for environmental quality, more resources available for cleaner technologies and a transition from manufacturing and agriculture-centered industries towards service-based industries. These components support the notion that the long run GDPpc-carbon emission relationship will eventually reach a threshold, leading to lower carbon emissions with greater economic growth. Ultimately this aligns with the goal of BRICS nations to harmonize economic development and environmental sustainability.

However, the results of the other two EKCs carry vital implications for the growth-emissions nexus. We find that there is a U-shaped relationship between urbanization and carbon emissions, indicating that initial urbanization does not pose a threat to carbon emissions. Only after a certain urbanization threshold is breached will long-run urbanization lead to higher levels of carbon emissions, potentially disrupting the environmental sustainability targets of BRICS nations. Since urbanization is a natural process of economic development, policymakers should focus on sustainable urban planning, renewable energy technology and innovations to reduce the harmful impact of the current urbanization trajectory. Without such measures, the ideal scenario of high growth and low emissions might remain unattainable.

Moreover, the inverted U-shape relationship between income inequality and carbon emissions may point to an alarming scenario where future carbon reductions might come at the expense of higher inequality. Reducing inequality remains a crucial objective for BRICS countries; therefore, policymakers should consider growth strategies that will lead to lower inequality while ensuring environmental sustainability. Overall, the success of BRICS countries in reaching climate change targets highly depends on policymakers' ability to maneuver between economic growth, urbanization, rising inequality and increasing carbon emissions.

References

Al-Mulali, U., & Ozturk, I. (2016). The investigation of environmental Kuznets curve hypothesis in the advanced economies: The role of energy prices. *Renewable and Sustainable Energy Reviews*, *54*, 1622–1631. https://doi.org/10.1016/j.rser.2015.10.131

Avenyo, E. K., & Tregenna, F. (2021). *The effects of technology intensity in manufacturing on CO2 emissions: evidence from developing countries* (No. 846). Cape Town, Southern Africa: Economic Research Southern Africa. https://econrsa.org/wp-content/uploads/2022/06/working_paper_846.pdf

Balsalobre-Lorente, D. Sinha, A., Driha, O. M., & Mubarik, M. S. (2021). Assessing the impacts of ageing and natural resource extraction on carbon emissions: a proposed policy framework for European Economies. *Journal of Cleaner Production*, 296, 126470. https://doi.org/10.1016/j.jclepro.2021.126470

Berthe, A., Elie L. (2015). Mechanisms explaining the impact of economic inequality on environmental deterioration. *Ecological Economics*, 116, 191–200. https://doi.org/10.1016/j.ecolecon.2015.04.026

Borghesi, S. (2006) Income inequality and the environmental Kuznets curve. In: *Environment, inequality and collective action* (pp. 33-51). Routledge.

Boyce, J.K. (1994). Inequality as a cause of environmental degradation. *Ecological Economics,* 11(3), 169–178. https://doi.org/10.1016/0921-8009(94)90198-8

Boyce, J., Klemer, A., Templet, P., & Willis, C. (1999). Power distribution, the environment and public health: a state-level analysis. *Ecological Economics,* 29(1), 127-140. https://doi.org/10.1016/S0921-8009(98)00056-1

Ciplet, D., Roberts, J.T., & Khan, M.R. (2015) *Power in a warming world: the new global politics of climate change and the remaking of environmental inequality.* MIT Press, Cambridge.

Fang, J., Gozgor, G., Mahalik, M.K., Mallick, H. & Padhan, H. (2022). Does urbanization induce renewable energy consumption in emerging economies? The role of education in energy switching policies. Energy Economics, 111, 106081. https://doi.org/10.1016/j.eneco.2022.106081

Gawande, K., Berrens, R. P., & Bohara, A. K. (2001). A consumption-based theory of the environmental Kuznets curve. *Ecological economics*, *37*(1), 101-112. https://doi.org/10.1016/S0921-8009(00)00269-X

Golley, J., & Meng, X. (2012) Income inequality and carbon dioxide emissions: the case of Chinese urban households. *Energy Economics*, 34(6), 1864–1872. https://doi.org/10.1016/j.eneco.2012.07.025

Grunewald, N., Klasen, S., Martínez-Zarzoso, I., & Muris, C. (2017). The Trade-off Between Income Inequality and Carbon Dioxide Emissions. *Ecological Economics*, *142*, 249–256. https://doi.org/10.1016/j.ecolecon.2017.06.034

Guo, L. (2014). Emissions and regional income disparity: evidence from China. *Singapore Economic Review*, 59(01), 1–20.

Hailemariam, A, Dzhumashev, R., & Shahbaz, M. (2020). Carbon emissions, income inequality and economic development. *Empirical Economics*, 59, 1139–1159. https://doi.org/10.1007/s00181-019-01664-x

Hao, Y., Chen, H., & Zhang, Q. (2016). Will income inequality affect environmental quality? analysis based on China's provincial panel data. *Ecological Economics*, 67, 533–542. https://doi.org/10.1016/j.ecolind.2016.03.025

Hasan, Md. B., Wieloch, J., Ali, Md. S., Zikovic, S., & Uddin, G. S. (2023). A new answer to the old question of the environmental Kuznets Curve (EKC). Does it work for BRICS countries? *Resources Policy*, *87*, 104332. https://doi.org/10.1016/j.resourpol.2023.104332

Heerink, N., Mulatu, A., & Bulte, E. (2001). Income inequality and the environment: aggregation bias in environmental Kuznets curves. *Ecological Economics*, 38(3), 359–367. https://doi.org/10.1016/S0921-8009(01)00171-9

Hundie, S. K. (2021). Income inequality, economic growth and carbon dioxide emissions nexus: empirical evidence from Ethiopia. *Environmental Science and Pollution Research*, *28*(32), 43579-43598. https://doi.org/10.1007/s11356-021-13341-7

IPCC. (2023). *Climate change 2023: Synthesis report*. UNEP. https://www.unep.org/resources/report/climate-change-2023-synthesis-report

Jorgenson, A., Schor, J., & Huang, X. (2017). Income inequality and carbon emissions in the United States: a state-level analysis, 1997-2012. *Ecological Economics*, 134, 40-48. https://doi.org/10.1016/j.ecolecon.2016.12.016

Khan, A., Muhammad, F., Chenggang. Y., Hussain, J., Bano, S., & Khan, M. (2023). The impression of technological innovations and natural resources in energy-growth-environment nexus: A new look into BRICS economies. *Science of The Total Environment*, 727, 138265. https://doi.org/10.1016/j.scitotenv.2020.138265

Kashwan, P. (2017). Inequality, democracy, and the environment: a cross-national analysis. *Ecological Economics*, 131, 139–151. https://doi.org/10.1016/j.ecolecon.2016.08.018

Kasuga, H. & Takaya, M. (2017) Does inequality affect environmental quality? Evidence from major Japanese cities. *Journal of Cleaner Production*, 142, 3689–3370. https://doi.org/10.1016/j.jclepro.2016.10.099

Knight, K.W., Schor, J.B., & Jorgenson, A.K. (2017). Wealth inequality and carbon emissions in high-income countries. *Social Currents*, 4(5), 403–412. https://doi.org/10.1177/2329496517704872

Liobikienė, G. (2020). The revised approaches to income inequality impact on production-based and consumption-based carbon dioxide emissions: literature review. *Environmental Science and Pollution Research*, *27*(9), 8980–8990. https://doi.org/10.1007/s11356-020-08005-x

Liobikienė, G., & Rimkuvienė, D. (2020). The role of income inequality on consumption-based greenhouse gas emissions under different stages of economic development. *Environmental Science and Pollution Research*, 27, 43067-43076. https://doi.org/10.1007/s11356-020-10244-x

Ma, N. Lia, H. Wang, Y. Fenga, S. Shia, J. and Wange, K. (2019). Interaction pattern features and driving forces of intersectoral CO2 emissions in China: A network motif analysis. *Resources, Conservation and Recycling*, 149: 391–4. https://doi.org/10.1016/j.resconrec.2019.03.006

Magnani, E. (2000) The Environmental Kuznets Curve, environmental protection policy and income distribution. *Ecological Economics*, 32(3), 431–443. https://doi.org/10.1016/S0921-8009(99)00115-9

Nyangena, O., Senelwa, V.K., & Igesa, S.B. (2019). Climate Change-Urbanization Nexus: Exploring the Contribution of Urbanization on Carbon Emissions in East Africa. *Journal of Scientific and Engineering Research*, 6(1), 158-165. https://ssrn.com/abstract=3330074

Okamoto, S. (2013). Impacts of Growth of a Service Economy on CO2 Emissions: Japan's Case. *Journal of Economic Structures*, *2*(1). https://doi.org/10.1186/2193-2409-2-8

Ota, T. (2017). Economic growth, income inequality and environment: assessing the applicability of the Kuznets hypotheses to Asia. *Palgrave Communications*, *3*, 17069. https://doi.org/10.1057/palcomms.2017.69

Parikh, J. & Shukla, V. (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. https://doi.org/10.1016/0959-3780(95)00015-G

Pata, U. K., & Caglar, A. E. (2020). Investigating the EKC hypothesis with renewable energy consumption, human capital, globalization and trade openness for China: Evidence from augmented ARDL approach with a structural break. *Energy*, 216, 119220. https://doi.org/10.1016/j.energy.2020.119220

Rahman, M.M., & Vu, X.B. (2020). The nexus between renewable energy, economic growth, trade, urbanisation and environmental quality: a comparative study for Australia and Canada. *Renewable Energy*, 155, 617-627. https://doi.org/10.1016/j.renene.2020.03.135

Ravallion, M., Heil, M., & Jalan, J. (2000). Carbon Emissions and Income Inequality. *Oxford Economic Papers*, *52*(4), 651–669. https://www.jstor.org/stable/3488662

Scruggs, L.A. (1998). Political and economic inequality and the environment. *Ecological. Economics*, 26, 259-275. https://doi.org/10.1016/S0921-8009(97)00118-3

Shahbaz, M., Loganathan, N., Muzaffar, A. T., Ahmed, K., & Ali Jabran, M. (2016). How urbanization affects CO 2 emissions in Malaysia? The application of STIRPAT model. *Renewable and Sustainable Energy Reviews*, *57*, 83–93. https://doi.org/10.1016/j.rser.2015.12.096

Sinha, A., Gupta, M., Shahbaz, M., & Sengupta, T. (2019). Impact of corruption in the public sector on environmental quality: Implications for sustainability in BRICS and next 11 countries. *Journal of Cleaner Production*, *232*, 1379–1393. https://doi.org/10.1016/j.jclepro.2019.06.066

Torras, M., & Boyce, J.K. (1998). Income, inequality, and pollution: a reassessment of the environmental Kuznets Curve. *Ecological Economics*, 25, 147-160. https://doi.org/10.1016/S0921-8009(97)00177-8

Ummalla, M., & Goyari, P. (2021). The impact of clean energy consumption on economic growth and CO2 emissions in BRICS countries: Does the environmental Kuznets curve exist? *Journal of Public Affairs*, 21(1), e2126. https://doi.org/10.1002/pa.2126

UN. (2023). *Emissions gap report 2023*. UNEP. https://www.unep.org/resources/emissions-gap-report-2023

Voumik, L. C., Sultana, R., & Dey, R. (2023). Investigating the EKC hypothesis with human capital index, nuclear energy, urbanization, and service sectors on the environment: evidence from BRICS countries. *World Development Sustainability*, 100060. https://doi.org/10.1016/j.wds.2023.100060

Wang, Q., Wang, X., & Li, R. (2022). Does urbanization redefine the environmental Kuznets curve? An empirical analysis of 134 Countries. *Sustainable Cities and Society*, 76, 1-14. https://doi.org/10.1016/j.scs.2021.103382

Wolde-Rufael, Y. & Idowu, S. (2017). Income distribution and CO2 emission: a comparative analysis for China and India. *Renewable Sustainable Energy Reviews,* 74: 1336-1345. https://doi.org/10.1016/j.rser.2016.11.149

World Bank. (2023). South Africa Overview: Development news, research, data. https://www.worldbank.org/en/country/southafrica/overview.

Xu, S., Li, Y., Miao, M., Gao, C., He, X., Shen, W., & Wang, X. (2018). Regional differences in nonlinear impacts of economic growth, export and FDI on air pollutants in China based on provincial panel data. *Journal of Cleaner Production*, 228, 455–466. https://doi.org/10.1016/j.jclepro.2019.04.327

Yang, Z., Abbas, Q., Hanif, I., Alharthi, M., Taghizadeh-Hesary, F., Aziz, B., & Mohsin, M. (2021). Short- and long-run influence of energy utilization and economic growth on carbon discharge in emerging SREB economies. *Renewable Energy*, *165*, 43–51. https://doi.org/10.1016/j.renene.2020.10.141

York, R., Rosa, E., & Dietz, T. (2003). STIRPAT, IPAT, and ImPACT: analytic tools for unpacking the driving forces of environmental impacts. *Ecological Economics*, 46, 351–365. https://doi.org/10.1016/S0921-8009(03)00188-5

Zhu, H., Xia, H., Guo, Y., & Peng, C. (2018). The heterogeneous effects of urbanization and income inequality on CO2 emissions in BRICS economies: evidence from panel quantile regression. *Environmental Science and Pollution Research*, *25*(17), 17176–17193. https://doi.org/10.1007/s11356-018-1900-y