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The Impact of Income Inequality, Renewable Energy Consumption, Non-Renewable Energy Consumption and Per Capita Income on Poverty: Evidence from BRICS Economies

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Abstract: The main purpose of this study is to investigate the role of income inequality, per capita renewable and per capita non-renewable energy consumption, per capita income on poverty reduction in BRICS (Brazil, Russia, India, China, South Africa) countries over the period between 1991–2019. This study used second-generation panel data methodologies taking into account cross-dependence between countries, which gives more accurate results. The outcomes of the panel ARDL unveiled that while an increase in income inequality and per capita non-renewable energy consumption increases poverty, an increase in growth and per capita renewable energy consumption decreases poverty. Based on the findings, policymakers should focus their efforts on developing an appropriate energy strategy that highlights the necessity of a renewable energy-driven economy powered by energy-saving technologies.

Keywords: poverty, energy consumption, income inequality, panel ARDL.

Introduction

Poverty not only encompasses lack of income and productive resources. Poverty encompasses lack of income and productive resources, as well as hunger and malnutrition, limited access to education and other basic services, social discrimination and exclusion, and lack of participation in decision-making processes (UN, 2021b). The eradication of poverty, which is a global problem, is among the main goals of international institutions. Poverty alleviation, the reduction of income inequality and the availability of modern energy are three of the most important agendas in the sustainable development goals (SDGs). The first aim of the SDG is to end poverty in all its forms everywhere. The 2030 Agenda recognizes that ending poverty in all of its forms and dimensions is the most pressing global challenge and a prerequisite for long-term development. The World Bank (2021) stated that global poverty rose in 2020 for the first time in over 20 years. Also, it was stated that approximately 100 million additional people are living in poverty due to the pandemic, and this figure will gradually increase. 736 million people still live in extreme poverty – hence, 10 percent of the world's population lives in extreme poverty. Some 1.3 billion people live in multidimensional poverty. Half of all people living in poverty are under 18. One person in every 10 is extremely poor (UN, 2021a). Moreover, poverty and inequality are exacerbated by climate disruptions, global health pandemics (like COVD-19) and macroeconomic shocks (Adeleye *et al*., 2020).

The impact of inequality on poverty reduction is larger than growth. However, most of the observed changes in poverty can be explained by changes in mean incomes (Bergstrom, 2020). Income inequality rose steadily in advanced economies and in some large emerging market economies. In advanced economies, poverty rates are low and GDP per capita growth has been slowing down every decade since the 1980s. In the developing countries, poverty rates have been declining. GDP per capita growth has accelerated in emerging markets and low-income countries, particularly since the 2000s (Cerra, Lama and Loayza, 2021). Despite the economic growth recorded in the developing countries, poverty and especially inequality are also observed (Adeleye *et al*., 2020).

Another important factor in reducing poverty is energy. Energy is an important input for both human and industrial development. This means that it is a crucial requirement for the sustainability and economic well-being of an economy (Rafindadi and Ozturk, 2017). Energy is one of the most basic inputs for people's livelihood and economy. Lack of access to adequate, affordable and clean energy sources harms people's living conditions, health and their ability to engage in productive activities. This can cause people to remain in poverty (Hussein, Leal Filho, 2012; Khobai, 2021). Energy can be used as one of the instruments to poverty alleviation, especially in the developing countries. None of the basic needs of people can be provided without energy (Hussein, Leal Filho, 2012). Renewable energy can help alleviate poverty by offering good jobs for the poor, in addition to enhancing energy security, boosting energy access, and mitigating climate change (Jairaj *et al*., 2017). Energy has been recognized as an important promoter of development (Diaz-Chavez *et al*., 2015). The relationship between energy and poverty reduction is manifold. The benefits that access to energy can create in poor regions are not to be ignored (Diaz-Chavez *et al*., 2015).

It is a well-known fact that renewable energy consumption has a positive effect on GDP (Inglesi-Lotz, 2016; Ito, 2017; Narayan and Doytch, 2017; Koçak and Şarkgüneşi, 2017). New employment opportunities will emerge when renewable energy investments are encouraged. Therefore, the more people are employed, the easier it will be to meet basic needs through poverty reduction (Zeb *et al*., 2014). In rural locations where opportunities are scarce, the lack of access to modern energy sources exacerbates poverty. Expanding access to electricity should be a part of the public policy aimed at eradicating poverty (Pereira, Freitas and da Silva 2010).

The rapid economic growth experienced in the BRICS countries has played an active role in reducing poverty. On the other hand, they have made significant progress in reducing poverty through policies such as employment and social protection measures. However, income inequality has emerged as a major challenge for the BRICS countries (ILO, 2020). Energy is a critical component of achieving sustainable development, which includes poverty reduction, social development, and environmental development (Hussein, Leal Filho, 2012; Kaygusuz, 2011). Therefore, in this study, the effect of income inequality, per capita renewable energy consumption, per capita non-renewable energy consumption and per capita income on poverty reduction are examined. While Sakanko and David (2018), Okwanya and Abah (2018) and Tsaurai (2021) examined the effect of the total energy consumption on poverty, Thiam (2011) and Khobai (2021) examined the effect of renewable energy consumption on poverty. However, neither the impact of renewable nor that of non-renewable energy consumption on poverty has ever been examined. Here, besides income inequality and per capita income, the effect of per capita renewable and non-renewable energy consumption on poverty is examined.

The BRICS countries have experienced significant economic growth over the past two decades. BRICS countries make up 40% of the world's population, contribute approximately 21% to the world's gross domestic product (GDP), and consume 40% of the world's energy (Danish and Wang, 2019: 1076; Ulucak, *et al*., 2020: 813). Despite all this, the BRICS countries are not in a position to reach SDG 1 (no poverty) in absolute terms (Vyas-Doorgapersad, 2021: 7). This study seeks to address the following key research questions: What impacts do income inequality, renewable energy consumption, non-renewable energy consumption and per capita income have on poverty in the context of the BRICS countries? The contribution of this study is as follows. First, this study does not concentrate only on the effect of income inequality and per capita income on poverty, but also on the impact of renewable energy consumption and non-renewable energy consumption on poverty as well. Second, we have incorporated income inequality and per capita income as an important control variable in the poverty model.

Considering the relationship between poverty and income inequality, renewable energy consumption, non-renewable energy consumption and per capita income, the following proposed hypotheses shall be tested in the empirical investigation:

H1: Income inequality has a negative influence over poverty reduction.
H2: Renewable energy consumption has a positive influence over poverty reduction.
H3: Non-renewable energy consumption has a negative influence over poverty reduction.
H4: Income has a positive influence over poverty reduction.

The rest of the paper is as follows: Section 2 reviews the relevant literature. Section 3 describes the data set and the empirical model. Section 4 reveals the result output. Section 5 provides conclusions.

1. Theoretical Framework

On the relationship between growth and poverty, there are two points of view. The trickle-down hypothesis is one of these two viewpoints, while the trickle-up theory is the other. According to the trickle-down theory, economic expansion is beneficial to poverty alleviation. According to this hypothesis, the benefits of a country's growth trickle down to the poor. As a result, increasing economic growth should be the goal if poverty is to be minimized. According to the trickle-up theory, economic expansion is bad for poverty alleviation. According to this hypothesis, the gains of a country's economic progress trickle down to the middle and upper classes (Todaro, 1997; Norton, 2002; Nyasha, Gwenhure and Odhiambo, 2017; Khobai, 2021). It has also been stated that the relationship between economic growth and poverty can be multidirectional (Hichem, 2016; Khobai, 2021); i) economic growth is considered as an important and necessary condition in reducing poverty due to the effects of inequality. ii) a high growth rate should be achieved if poverty is to be reduced in the long run. iii) poverty reduction can be achieved when growth sources are expanded. iv) the effects of growth on poverty differ between countries due to many factors.

The relationship between energy consumption and poverty has been investigated in the literature (Foster, Tre and Wodon, 2000; Foster and Tré, 2003; Barnes, Khandker and Samad, 2010; Khandker, Barnes and Samad, 2012). The relationship between energy consumption and poverty has been explained by the energy transition theory (Hosier and Dowd, 1987; Leach, 1992). According to this theory, energy use and per capita income are inextricably linked. According to this notion, when a person's income level rises, they are more likely to transition from traditional to modern energy. High-income countries use more contemporary and modern energy than low-income countries. As a result, having access to modern energy raises income levels and helps to alleviate poverty (Okwanya and Abah, 2018; Kousar and Shabbir, 2021).

2. Literature

2.1. Income inequality, growth and poverty

The nexus between income inequality, growth and poverty has been investigated in many studies (Alesina and Rodrik,1994; Deininger and Squire, 1996; Barro, 2000; Forbes, 2000; Dollar and Kraay, 2002; Sasmal and Sasmal, 2016; Anikin and Tikhonova, 2016; Dollar, Kleineberg and Kraay, 2016; Nyasha, Gwenhure and Odhiambo, 2017; Marrero and Servén, 2018; Nansadiqa, Masbar and Majid, 2019; Feriyanto, El Aiyubbi and Nurdany, 2020; Dada and Fanowopo, 2020; Zaman *et al*., 2020; Hailemariam and Dzhumashev, 2020). Growth and income inequality, according to Cheema and Sial (2012), play a significant impact in affecting poverty in Pakistan. To alleviate poverty, the government should enact measures that promote economic growth while also improving income distribution. According to Nyasha, Gwenhure and Odhiambo (2017), growth strategies should be prioritized because, in the long run, economic growth contributes to poverty reduction in Ethiopia. This would ensure that poverty is reduced as much as possible. Michálek and Výbošťok (2019) examine relationship between growth, income inequality and poverty in Europa for the period of 2005–2015. The result revealed that growth and income inequality have a negative and positive effect on poverty, respectively. Zaman *et al*. (2011) examine the impact of economic growth and income inequality on poverty in India, Nepal, Pakistan and Sri Lanka. The study revealed that economic growth and income inequality reduce poverty.

There are also studies showing that there is a positive relationship between economic growth and poverty. Aigbokhan (2000) examined the relationship between poverty, inequality and economic growth in Nigeria for the period of 1986–1996. The study revealed that there is a positive relationship between growth and poverty. Stephen and Simeon (2013) revealed that there is a positive relationship between economic growth and poverty in Nigeria. Tridico (2010) showed that growth did not reduce poverty, and income inequality worsened in 50 emerging and transition economies for the period of 1995–2006. Nuruddeen and Ibrahim (2014) showed that an increase in GDP in Nigeria caused a high level of poverty.

Table 1 summarizes the literature focusing on the relationship between income inequality, economic growth, and poverty. The results in the literature generally revealed that there is a negative relationship between growth and poverty, and a positive relationship between income inequality and poverty. This evidence emphasizes the importance of economic growth and income inequality for poverty.

Table 1

Literature on the relationship between economic growth, income inequality and poverty

Author	Country / Period	Method	Conclusion
Mulok *et al.* (2012)	Malaysia/1970-2009	ARDL	economic growth reduces poverty
Stephen and Simeon (2013)	Nigeria/1980-2008	OLS	economic growth reduces poverty
Nuruddeen and Ibrahim (2014)	Nigeria/2000-2012	ARDL, Granger causality test	increase in growth causes high level of poverty
Hassan, Zaman and Gul (2015)	Pakistan/1980-2011	ECM	inequality increases poverty
Soylu (2015)	Canada/1976-2015	ARDL	growth and income inequality affect poverty negatively and positively, respectively
Nyasha, Gwenhure and Odhiambo (2017)	Ethiopia/1970-2014	ARDL	economic growth reduces poverty
Garza-Rodriguez (2018)	Mexico/1960-2016	Gregory-Hansen cointegration, VECM	economic growth reduces poverty
Sehrawat and Giri (2018)	India/1970-2015	ARDL	while economic growth decreases poverty, inequality increases poverty
Leow and Tan (2019)	145 countries/1982–2017	GMM	economic growth and inequality decrease and increase poverty, respectively
Dada and Fanowopo (2020)	Nigeria/1984–2018	ARDL	economic growth reduces poverty
Zaman *et al.*, (2020)	124 countries/2010–2013	PMG	income inequality and mean income increases and decreases poverty, respectively
Feriyanto, El Aiyubbi and Nurdany (2020)	Indonesia/2010–2019	FE	GRDP reduces poverty
Omar and Inaba (2020)	116 developing countries/2004-2016	FE	income inequality increases poverty
Alam (2020)	23 countries/1990–2014	PCSE, dynamic panel GMM	negative linear relationship between growth and poverty, non-linear relationship between growth, poverty and inequality
Anser *et al.*, (2020)	16 diversified countries/1990–2014/	GMM	growth reduces poverty
Chishti, Rehman and Murshed (2021)	Pakistan/1972–2018	NARDL	per capita income reduce the poverty
Imimole (2021)	Nigeria/1980–2019	Granger Causality test, ARDL	inequality and growth impact poverty positively and negatively, respectively
Solarin (2021)	30 developing countries/2010–2019/	GMM	real GDP per capita reduces income poverty and health poverty

2.2. Energy consumption and poverty

The link between energy and poverty is a result of the link between energy and economic growth. The energy utilized in manufacturing has a significant impact on poverty reduction. When energy is used by the poor to earn or enhance their income, it has a direct influence on poverty (Cabraal, Barnes and Agarwal, 2005). Okwanya, Moses and Alhassan

(2015) emphasized that it is important to make energy available in order to increase employment and income level and reduce poverty in Nigeria. Okwanya and Abah (2018) emphasized that, in order to maximize the impact of energy consumption on poverty reduction, governments in 12 African countries need to improve the energy-related infrastructure and maintain political stability. Chirambo (2018) revealed that electrification can stimulate economic growth, reduce youth unemployment, reduce inequality and alleviate poverty in Sub-Saharan Africa. Mboumboue and Njomo (2016) stressed that by enhancing the standard of living and the quality of life, energy plays a critical role in social and economic growth. Energy is important for environment, macroeconomic growth, overcoming poverty, expanding employment opportunities, gender equality, education and health, promoting human development (UNDP, 2005). Availability and affordability of modern energy resources should be increased in order to reduce poverty and increase income level (Sakanko and David, 2018).

Also, there are some studies in the literature focusing on the relationship between the adoption of alternative renewable energy sources and poverty reduction. Geall and Shen (2018) analyzed the role of solar photovoltaic (PV) technologies in poverty reduction in China. They revealed that solar energy systems were not effective in improving living standards for most nomadic households. A more flexible PV-based intervention approach, according to Liao and Fei (2019), can have a stronger impact on poverty reduction in China's remote rural areas. Zhang *et al.* (2020) found that photovoltaic investment is positive and significant in reducing poverty in China. Li *et al.* (2020) verified the impact of solar PV poverty alleviation in China. Liu *et al.* (2021) analyzed the role of solar PV to livelihood improvements in rural China. They revealed that the impact of solar PV plants on poverty alleviation varies by region.

The literature on the association between energy consumption and poverty is summarized in Table 2. As seen in the table, in general, energy consumption reduces poverty. On the other hand, while modern energy reduces poverty, non-modern energy increases poverty.

Table 2

Literature on the relationship between energy consumption and poverty

Author	**Period /Country**	**Method**	**Conclusion**
Thiam (2011)	Senegal/1990-2005	life-cycle-cost approach	energy consumption reduces poverty
Ngepah (2011)	South Africa/1993-2008	OLS	while gasoline, kerosene and coal increase poverty, gas and diesel have significant poverty reducing effects
Okwanya, Moses and Alhassan (2015)	Nigeria/1990-2011	OLS, Granger Causality test	energy consumption reduces poverty
Okwanya and Abah (2018)	12 African countries/1981-2014	FMOLS	energy consumption reduces poverty
Sakanko and David (2018)	Nigeria/2006	descriptive statistics and logit regression model	energy consumption reduces poverty
Aghaei and Rezaghoizadeh (2018)	Iran/1984-2010	2SLS and 3SLS	natural gas and electricity are more effective to reduction of poverty
Nwani and Osuji (2020)	20 Sub-Saharan African countries/1990-2018	PLS and RLS	the impact of energy consumption on HDI is positive
Aghaei and Lin Lawell (2020)	Iran/1989-2018	2SLS and 3SLS	energy consumption decreases poverty
Khobai (2021)	South Africa/1990-2018	ARDL and VECM	REC reduces poverty
Ogbeide-Osaretin (2021)	Nigeria/1990-2017	ARDL	Non-modern sources of energy consumption increase poverty while electricity reduces poverty
Tsaurai (2021)	BRICS/1995-2018	FE, pooled OLS, RE, FMOLS	energy consumption reduces poverty
Kousar and Shabbir (2021)	Pakistan/1985-2017	ARDL	energy consumption reduces poverty

Abbreviations **For Table 1 and Table 2; ARDL, Autoregressive Distributed Lag; NARDL, nonlinear ARDL; OLS, Ordinary Least Squares; ECM, Error Correction Model; VECM, Vector Error Correction Model; GMM, Generalized Method of Moments; PMG, Pooled Mean Group; FE, Fixed Effect; RE, Random Effect; FMOLS, Fully Modified Least Squares; 2SLS, Two-Stage Least Squares; 3SLS, Three-Stage Least Squares; PCSE, Panel Corrected Standard Error; PLS, Panel Least Square; RLS, Robust Least Square; GRDP, Real Gross Regional Domestic Product.**

3. Empirical model and data

3.1. Data

The study uses panel data of BRICS (Brazil, Russia, India, China and South Africa) countries from 1991.2019. The study's variables are poverty, income inequality, per capita renewable energy consumption, per capita non-renewable energy consumption and per capita income. All variables are in the logarithmic form. The panel version of the empirical model is constructed as follows:

$$\ln POV_{it} = \delta_0 + \delta_1 \ln INEQ_{it} + \delta_2 \ln REC_{it} + \delta_3 \ln NREC_{it} + \delta_4 \ln GDP_{it} + \varepsilon_{it} \quad (1)$$

where i, t and ε_{it} refer to cross-sections (countries), the time period (years), and the residual term, respectively. $\ln POV_{it}$ is the natural log of the poverty reduction, $\ln INEQ_{it}$ is the natural log of income inequality, $\ln REC_{it}$ is the natural log of per capita renewable energy consumption, $\ln NREC_{it}$ is the natural log of per capita non-renewable energy consumption and $\ln GDP_{it}$ is the natural log of per capita income.

The variables used in the study are measured as follows: different variables are used as measures of poverty in empirical studies. Headcount-based data for the poor (Omar and Inaba, 2020; Baloch *et al*., 2020; Kousar and Shabbir, 2021; Solarin, 2021; Ogbeide-Osaretin, 2021), income (Adekoya, 2018), infant mortality (Tsaurai, 2018; Magombeyi and Odhiambo, 2018; Khobai, 2021; Solarin, 2021), life expectancy (Magombeyi and Odhiambo, 2018; Tsaurai, 2018), multidimensional poverty index (Aziz *et al*., 2020; Osinubi and Olomola, 2020) and human development index (Nwani and Osuji, 2020) are used as proxy for poverty in some studies. Some other studies used per capita consumption expenditure as proxy for poverty due to the lack of data on poverty (Quartey, 2008; Odhiambo, 2009; Odhiambo, 2011; Nayasha, Gwenhure and Odhiambo, 2017; Sehrawat and Giri, 2018; Adeleye *et al*., 2020; Dada and Fanowopo, 2020; Garidzirai and Matiza, 2020). The consumption expenditures of the poor are generally more reliably reported and more stable than income (Ravallion, 1992; Datt and Ravallion, 1992; Quartey, 2008; Sehrawat and Giri, 2016; Sehrawat and Giri, 2018). Therefore, in this study, per capita consumption expenditures are used as a proxy variable for the poverty reduction variable, as in the studies of Nayasha, Gwenhure and Odhiambo (2017), Sehrawat and Giri (2018), Dada and Fanowopo (2020) and Garidzirai and Matiza (2020). Per capita consumption expenditure is measured in USD (current). The income share of the top 10% (P10) is used as a proxy of income inequality. The income share of the top ten percent (P10) refers to the top ten percent of earners, representing capital concentration. Furthermore, this measure is capable of sensitively capturing changes in wealth disparity. As more wealth is concentrated in the hands of a smaller number of people, it becomes a significant indicator of rising inequality (Wu and Xie, 2020). In this study, the income share of the top 10% (P10) is used as a proxy variable for the income inequality variable, as in Wu and Xie (2020) and Saha and Mishra (2020). Wind, hydro, and nuclear energy sources are used as a proxy for renewable energy consumption, coal, oil, and gas are used as a proxy for non-renewable energy consumption as in Mahmood, Wang and Hassan (2019). Per capita income is measured in USD (current) and used as a proxy for economic growth. Per capita consumption expenditures (as proxy for poverty reduction.) and per capita income are gathered from the World Bank (2021) database. Both per capita renewable and per capita non-renewable energy consumption data are collected from the BP Statistical Review (2021). Income inequality is extracted from the World Inequality Database (2021).

3.2. Methodology

Before the econometric model estimation, some preliminary tests are performed. These tests are cross-sectional dependence (CSD), slope homogeneity analysis, and unit root analysis. Panel data techniques that overlook the CSD are claimed to produce stationarity and cointegration features that are biased and inconsistent (Destek, Ulucak and Dogan, 2018; Murshed, Haseeb and Alam, 2021). Since the first generation unit root and cointegration tests ignore the CSD, the applications of these methods are no longer valid in the presence of CSD (Li *et al*., 2021). Ignoring CSD in the model predictions may lead to an estimator efficiency loss and invalid test statistics (Lau *et al*., 2019). Due to trade internationalization, financial integration and globalization, any shock experienced in one country is also experienced in other countries (Qamruzzaman and Jianguo, 2020: 831). Since BRICS countries have similar economic characteristics, the investigation of the presence of cross-section dependency testing is important. Therefore, the presence of CSD among BRICS countries is tested first.

One of the tests developed to examine the CSD is the Lagrange Multiplier (LM) test (Breusch and Pagan, 1980), and this test is conducted by using the following equation:

$$y_{it} = \alpha_i + \beta_i x_{it} + \varepsilon_{it} \quad i = 1 \ldots, N \quad ve \quad t = 1 \ldots, T \tag{2}$$

In the Equation above, *i* and *t* denote the cross-section dimension and time period, respectively. While the null hypothesis of this test is expressed as there is no CSD between the units , the alternative hypothesis is expressed as there is a CSD between the units. The LM test is computed with the following formula:

$$LM = T\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}^2 \sim X^2_{N(N-1)/2} \tag{3}$$

where is the simple correlation coefficient between the residuals obtained from the ordinary least squares (OLS) and estimation of each equation. The LM test is an appropriate test when *N* is small and *T* is large enough. Pesaran (2004) states that this test cannot be applied when *N* is large. For large panels with $T \rightarrow \infty$ and $N \rightarrow \infty$, Pesaran (2004) proposed a scaled version of the LM test. The CD_{LM} version developed by Pesaran (2004) is as follows:

$$CD_{LM} = \sqrt{\frac{1}{N(N-1)}}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\left(T\hat{\rho}_{ij}^2 - 1\right) \sim \mathrm{N}(0,1) \tag{4}$$

Pesaran (2004) developed a more comprehensible test because the CD_{LM} test tends to dimension failures when *N* is large and *T* is small. The computation of the CD test developed by Pesaran (2004) is as follows:

$$CD = \sqrt{\left(\frac{2T}{N(N-1)}\right)}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\left(\hat{\rho}_{ij} - 1\right) \sim \mathrm{N}(0,1) \tag{5}$$

In other cases, however, if the population average pair-wise correlations are zero, the CD test will be ineffective. As a result, Pesaran *et al.* (2008) propose a bias-adjusted test, a modified version of the LM test. The bias-adjusted LM test (LM_{adj}) is:

$$LM_{adj} = \sqrt{\left(\frac{2}{N(N-1)}\right)}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}\frac{(T-k)\hat{\rho}_{ij}^2 - \mu_{Tij}}{\sqrt{\nu_{Tij}^2}} \sim \mathrm{N}(0,1) \tag{6}$$

where respectively are the number of regressors, the exact mean, and the variance of.

In addition, the test developed by Pesaran and Yamagata (2008) was applied to check the slope homogeneity issue.

The computation of the cross-sectional ADF (CADF) regression, as developed by Pesaran (2007), which takes into account cross-sectional dependence, is as follows:

$$\Delta y_{it} = \alpha_i + \rho_i y_{it-1} + \beta_i \bar{y}_{t-1} + \sum_{j=0}^{k} \gamma_{ij} \Delta \bar{y}_{it-1} + \sum_{j=0}^{k} \delta_{ij} y_{it-1} + \varepsilon_{it} \tag{7}$$

Where αi is the deterministic term, k is the lag length, and is the cross-sectional mean of time t. Following the above equation, t-statistics are obtained by calculating individual ADF statistics. Also, CIPS is taken from the average CADF statistic for each i as follows:

$$CIPS = \left(\frac{1}{N}\right) \sum_{i=1}^{N} t_i (N, T) \tag{8}$$

Pesaran (2007) provides the critical values for the CIPS test.

The DH approach permits to obtain heterogeneous slope coefficients and considers the cross-section dependence (Erdogan, Okumus and Guzel, 2020: 23659). Westerlund (2008) Durbin-Hausman (D-H) cointegration method was used to examine the validity of the long-term relationship between income inequality, per capita renewable energy consumption, per capita non-renewable energy consumption, per capita income and poverty reduction. The D-H approach is used to deal with CSD and heterogeneity (Amin, Jamasb and Nepal, 2021: 426). Also, the D-H approach could be applied in case of the regressor(s) being stationary. The D-H panel cointegration test does not require any prior knowledge of the variables' integration order (Erdogan, Okumus and Guzel, 2020; Amin, Jamasb and Nepal, 2021).

D-H test is divided into two categories as D-H Panel (DH_p) test and D-H Group (DH_g) test. Both can be defined as follows:

$$DH_p = \hat{S}_n (\tilde{\phi} - \hat{\phi})^2 \sum_{i=1}^{n} \sum_{t=2}^{T} \hat{e}_{it-1}^2 \qquad DH_g = \sum_{i=1}^{n} \hat{S}_i (\tilde{\phi}_i - \hat{\phi}_i)^2 \sum_{t=2}^{T} \hat{e}_{it-1}^2 \tag{9}$$

While the DH-group statistic assumes that the autoregressive parameters are heterogeneous, the DH-panel statistic assumes that the autoregressive parameters are homogeneous. DH*p* tests $H_0 = \phi i = \phi = 1$ for all cross-sections against $H_1 = \phi_i = \phi < 1$ for all cross-sections in the panel dataset. On the other hand, DHg tests $H_0 = \phi_i = 1$ for all cross-sections against $H_0 = \phi_i < 1$ for at least one cross-section within the panel dataset (Westerlund, 2008).

In the study, the long-run and short-run relationships between income inequality, per capita renewable energy consumption, per capita non-renewable energy consumption, per capita GDP and poverty reduction are examined via the panel autoregressive distributed lag (ARDL). The importance of the temporal dimension of the panel under consideration offers the possibility of a long-term relationship between the variables and the resulting causal links (Attiaoui and Boufateh, 2019: 13337). For this, the ARDL method was applied. The study uses two estimators which are suggested by the panel ARDL method. The first technique, namely Mean Group (MG), was developed by Pesaran and Smith (1995). The second technique, namely Pooled Mean Group (PMG), was developed by Pesaran *et al*. (1999). The panel ARDL approach is an econometric technique that offers a number of benefits. The following are some of the benefits: i) The panel ARDL framework generates both short-run and long-run estimates at the same time. ii) The panel ARDL approach is appropriate when variables have different integration levels, such as I(0), I(1), or mixed. iii) The panel ARDL technique is a panel cointegration technique for estimating dynamic panels with variable estimated parameters across countries. iv) The panel ARDL model uses the error correction model (Tarazkar *et al*., 2020; Sulaiman and Abdul-Rahim, 2020; Shafique *et al*., 2021). A comparison and choice between PMG and MG estimators is required in terms of efficiency and consistency. For this, the Hausman test is applied.

The relationship between income inequality, per capita renewable energy consumption, per capita non-renewable energy consumption, per capita GDP, and poverty reduction in BRICS countries following the panel ARDL(p,q) model equation is shown by Equation (10):

$$\ln POV_{it} = \varphi_{it} + \sum_{j=1}^{p} \vartheta_{ij} \ln POV_{it-j} + \sum_{j=0}^{q} \delta_{ij} \ln X_{it-j} + \varepsilon_{it} \tag{10}$$

where i = 1, 2,..., N represents the cross-sectional unit, t represents the time, j represents the number of time lags, p represents the lag of the dependent variable, and q represents the lag of independent variables. Also, X_{it} represents the vector of independent variables (income inequality, per capita renewable energy consumption, per capita non-renewable energy consumption, per capita GDP).

4. Results and Discussions

Before applying the panel data technique, we first examined the presence of panel variables of CSD by using the CSD tests (Breusch and Pagan (1980) LM test, Pesaran (2004) CD_{LM} test, Pesaran (2004) CD test and Pesaran, Ullah and Yamagata (2008) LM_{adj} test). According to the results given in Table 3, the null hypothesis of CSD is rejected. Hence, each of our series confirm the presence of CSD. For this reason, the second generation panel data method, which takes CSD into account, was applied in the study. According to the results of the Pesaran and Yamagata (2008) test which helps to examine the heterogeneity of the slope coefficients, the presence of slope heterogeneity in the data was determined. Table 3 reveals the slope heterogeneity test result.

Table 3

Results for CSD and slope homogeneity tests

Tests	ln*POV*	ln*GINI*	ln*REC*	ln*NREC*	ln*GDP*
CSD (constant)					
LM (Breusch, Pagan 1980)	31.737[a]	31.272[a]	29.057[a]	22.509[b]	26.354[a]
CD_{LM} (Pesaran, 2004)	4.860[a]	4.757[a]	4.261[a]	2.797[a]	3.657[a]
CD (Pesaran, 2004)	-2.693[a]	-3.477[a]	-3.544[a]	-3.459[a]	-2.416[a]
LM_{adj} (PUY, 2008)	9.578[a]	4.203[a]	3.790[a]	9.764[a]	6.397[a]
CSD (constant and trend)					
LM (Breusch,Pagan 1980)	30.896[a]	28.827[a]	35.534[a]	20.781[b]	21.840[a]
CD_{LM} (Pesaran 2004)	4.672[a]	4.210[a]	5.710[a]	2.411[a]	2.647[a]
CD (Pesaran 2004)	-2.685[a]	-3.245[a]	-3.270[a]	-3.298[a]	-2.496[a]
LM_{adj} (PUY, 2008)	8.969[a]	3.579[a]	3.530[a]	9.414[a]	5.910[a]
Homogeneity tests					
$\hat{\Delta}$	10.068[a] (0.000)				
$\hat{\Delta}_{adj}$	11.067[a] (0.000)				

Note: Probability values are in parentheses. a and b denote 1% and and 5% levels of significance, respectively. Δ# denotes delta, Δ#adj denotes adjusted delta.

Since CSD and slope heterogeneity are determined, the stationarity of the variables is examined with the CIPS test, which is the second generation unit root test. The results from the CIPS unit root tests are presented in Table 4. CIPS test estimates both the constant and the constant and trend. The CIPS unit root test revealed that all variables are stationary at the first difference. The test shows that all series are integrated at I(1).

Since the variables have been determined to have a long-run relationship, the impact of each independent indicator on poverty reduction should be evaluated. The Panel ARDL (MG and PMG) estimator is then used to investigate the effect of the specified explanatory variables on poverty reduction for the entire panel. The Hausman test statistic is presented in Table 6. The Hausman test statistic is equal to 5.82 with a .-value =0.757 and is insignificant. The Insignificant Hausman test accepted that PMG is a more efficient estimator than MG. Therefore, only the results of the PMG method are considered and interpreted.

Table 4

Results for CIPS unit root tests

Variables	**Level**		**First difference**	
	constant	**constant and trend**	**constant**	**constant and trend**
ln*POV*	-1.888	-2.136	-4.601[a]	-4.655[a]
ln*GINI*	-3.602	-1.784	-3.650[a]	-3.658[a]
ln*REC*	-1.865	-2.147	-4.981[a]	-4.977[a]
ln*NREC*	-2.571	-1.918	-3.589[a]	-3.748[a]
ln*GDP*	-2.038	-2.368	-4.673[a]	-4.812[a]

Note: At constant 1%, 5%, and 10% critical values for CIPS are -2.57, -2.33 and -2.21, respectively. At constant and trend 1%, 5%, and 10% critical values for CIPS are -3.1, -2.86 and -2.73, respectively. a is the 1% levels of significance.

After confirming the CSD, slope heterogeneity and stationarity properties of the series, the second generation panel cointegration test, as developed by Westerlund (2008) which is robust under the presence of CSD, is applied. Table 5 reveals the D-H result. The D-H test indicates that the alternative hypothesis of cointegration is strongly accepted. In that case, there exists a long-run relationship between income inequality, per capita renewable energy consumption, per capita non-renewable energy consumption, per capita GDP and poverty reduction.

Table 5

Result of the DurbinHausman cointegration test

	Stattistic	***p*–value**
Constant		
DH_g	16.080[a]	0.000
DH_p	45.644[a]	0.000
Constant and trend		
DH_g	3.122[a]	0.001
DH_p	11.630[a]	0.000

Note: a, b and c denote 1%, 5%, and 10% levels of significance, respectively.

Table 6
Result of Pooled Mean Group and Mean Group estimation

Variables	Coefficient	Std. Error	t-statistic	*p*-value
Long-run result (PMG)				
ln*GINI*	-0.130	0.033	-3.89	0.000[a]
ln*REC*	0.047	0.019	2.42	0.016[b]
ln*NREC*	-0.122	0.039	-3.14	0.002[a]
ln*GDP*	1.030	0.012	84.01	0.000[a]
Long-run result (MG)				
ln*GINI*	-0.437	0.105	-4.15	0.000[a]
ln*REC*	-0.099	0.224	-0.44	0.658
ln*NREC*	-0.453	0.301	-1.51	0.132
ln*GDP*	1.116	0.074	14.98	0.000[a]
Short-run result (PMG)				
Δln*GINI*	-0.212	0.152	-1.39	0.164
Δln*REC*	-0.152	0.077	-1.96	0.050[c]
Δln*NREC*	-0.316	0.145	-2.18	0.029[b]
Δln*GDP*	0.586	0.113	5.18	0.000[a]
C	-0.639	0.187	-3.42	0.001[a]
ECT(-1)	-0.372	0.115	-3.22	0.001[a]
Short-run result (MG)				
Δln*GINI*	0.006	0.043	0.15	0.879
Δln*REC*	-0.214	0.145	-1.48	0.139
Δln*NREC*	-0.171	0.097	-1.75	0.080[c]
Δln*GDP*	0.443	0.166	2.67	0.008[a]
C	-5.190	3.749	-1.38	0.166
ECT(-1)	-0.513	0.156	-3.27	0.001[a]
Hausman Test				
H_0=PMG	5.82 (0.757)			
H_1=MG				

Note: a, b and c denote 1%, 5%, and 10% levels of significance, respectively.

In this study, poverty reduction is used as a proxy for per capita consumption expenditure. As Sehrawat and Giri (2018) stated in their study, per capita consumption expenditure means poverty reduction. According to the results of the PMG estimator (Table 6), the income inequality and per capita non-renewable energy consumption are negatively and significantly related to the poverty reduction. The result indicates that an increase in income inequality by 1% is linked with a decrease of the per capita consumption expenditure by -0.130%. An increase in per capita non-renewable energy consumption by 1% is linked with a decrease of the per capita consumption expenditure by -0.122%. These findings imply that income inequality and per capita non-renewable energy consumption worsen poverty reduction. While the high growth performance in the BRICS countries led to significant decreases in poverty, the decrease in income inequality was not as prominent as the decrease in poverty. Therefore, the increase in income inequality increased poverty. These findings are parallel to the findings documented by Zaman *et al.* (2020) for 124 countries and by Omar and Inaba (2020) for 116 developing countries. Non-renewable energy consumption is an essential role for the BRICS countries. However, while the increase in non-renewable energy consumption is an important input for the industry, it increases poverty. The findings corroborate the results produced by Ogbeide-Osaretin (2021) for Nigeria.

On the other hand, the per capita renewable energy consumption and the per capita income are positively and significantly related to the poverty reduction. An increase in per capita renewable energy consumption by 1% is linked with an increase of the per capita consumption expenditure by 0.047%. An increase in per capita income by 1% is linked with an increase of the per capita consumption expenditure by 1.030%. These findings imply that per capita renewable energy consumption and per capita income help poverty reduction. This explains the role of renewable energy in reducing poverty. This also indicates that the BRICS countries are on the right path towards attaining poverty alleviation goals via the advancement of renewable energy technologies. These findings are consistent with the results documented in the studies by Thiam (2011) and Khobai (2021) for Senegal and South Africa, respectively. The BRICS countries could take a more active role in the fight against poverty by using the information and technologies necessary for growth through sustainable development. Similar findings were reported for the case of Mexico by Garza-Rodriguez (2018), for the case of Nigeria by Dada and Fanowopo (2020), and for the case of Pakistan by Chishti, Rehman and Murshed (2021). The error correction term is -0.372, and it is statistically significant. As Uzar (2020) stated, this result refers that it converges to balance in the long-run.

Conclusion and policy recommendations

The main purpose of this study was to examine the relationship between income inequality, per capita renewable energy consumption, per capita non-renewable energy consumption, per capita income and poverty in the BRICS countries. The annual data from 1991–2019 were applied for the analysis. Stationarity was checked among the variables by using the CIPS unit root test. Cointegration was examined among the variables by using the Durbin-Hausman cointegration test. The Panel ARDL (MG and PMG) method was used to reveal the variable linkages with the short-run and long-run analysis. Study outcomes during the long-run per capita income and per capita renewable energy consumption have positive interaction on the household consumption expenditure. This means that growth and renewable energy consumption reduce poverty. On the other hand, the variables income inequality and per capita non-renewable energy consumption demonstrated an adverse influence on household consumption expenditure. This means that income inequality and per capita non-renewable energy consumption increase poverty.

Depending upon the estimates, the BRICS countries should take the appropriate measures to reduce poverty. It is often believed that poverty is a rising global concern now and that future conventional strategies by all countries should concentrate on reducing poverty. The BRICS countries should increase their per capita income and renewable energy investments and consumption to reduce poverty. In addition, they can reduce poverty by reducing the share of non-renewable energy consumption in the total energy consumption and by ensuring an equal distribution of income among individuals. Also, the BRICS countries should focus their efforts on developing an appropriate energy strategy that highlights the necessity of a renewable energy-driven economy powered by energy-saving technologies.

Poverty is increasing despite the improvements in the BRICS countries as inequalities in health and education continue to be significant, deficiencies in social infrastructure are not remedied, the actual impact of economic growth on reducing poverty is insufficient, and subsidies to the energy sector crowd out spending in the social sector. Therefore, in order to achieve the poverty reduction target of the SDG in the BRICS countries, it is necessary to reduce the inflation rate and ensure price stability in the BRICS countries.

Giving more importance to policies for redistribution and structural transformation in the BRICS countries can play an active role in reducing the growing inequality. If poor people have limited access to energy, they will be more likely to remain poor. By energy being made cheaper, more poor people can benefit from energy. For this, the poor people's access to energy should be provided in an adequate and reliable way and at competitive prices. Ensuring energy access must be done in a sustainable way. Access to non-renewable energy is easier than access to renewable energy. Therefore, access to renewable energy consumption should be increased to overcome poverty. By shifting the investments made in the non-renewable energy sector to the renewable energy sector, poverty can be reduced by creating new business areas and employment. On the other hand, by reducing the negative impact of non-renewable energy consumption on the environment, its negative impact on the poor can be alleviated. Policy incentives for renewable energy should be adopted in order to ensure access to renewable energy and increase its consumption. By providing appropriate and sufficient energy, the negative impact of energy on poverty can be reduced.

Our motivation is to examine the impact of income inequality, renewable energy consumption per capita, non-renewable energy consumption per capita, and per capita income on poverty. This study is limited to the fact that factors such as investments in the renewable energy sector, environmental performance and externalities arising from non-renewable energy consumption are not taken into account for any reason. For this reason, it is recommended to conduct a study that takes into account the effects of factors such as investments in the renewable energy sector, environmental performance and externalities arising from non-renewable energy consumption on poverty.

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