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Abstract: *Biomass energy consumption has become a popular issue among policymakers in recent years due to its environmental repercussions. Biomass is one of the most common traditional easy sources of energy, and various studies have demonstrated its effects to health and the economy. However, there is a paucity of evidence on the use of biomass energy to mitigate climate change. This study explores the relationship between biomass energy consumption and ecological footprint in Bazil, Russia, India, China and South Africa (BRICS) countries during the period of 1990-2017. For this purpose, we employed augmented mean group (AMG) panel data estimator addressing the heterogeneity and problem of cross-sectional dependency in the panel data series. The results indicate that biomass energy consumption raises the ecological footprint of the BRICS nations. Policies are proposed to reduce the negative impact of biomass energy on the environment based on these findings.*

Keywords: biomass; ecological footprint; BRICS.

1. INTRODUCTION

To achieve sustainable development goals, all countries must work closely together in three dimensions: economic, environmental, and social. As a result, environmental safety is a major issue for policymakers worldwide. People in all nations and regions, particularly the poorest and utmost vulnerable, are adversely affected by environmental issues such as global warming, climate change, and air pollution. As a result, immediate efforts and strategies are needed to combat climate change, avoid global warming, and minimize air pollution. One possible answer is to replace fossil fuels, which account for 80% of worldwide primary energy consumption and 75% of greenhouse gas emissions, with renewable energy such as biomass, wind, geothermal, and solar energy. The majority of academics agree that using renewable energy helps to reduce carbon emissions and avoid environmental deprivation [1–4]. Renewable energy has recently been developing at a significant rate, owing to energy efficiency improvements, scientific and technical developments, and supportive regulations [5,6].

Biomass is the most abundant renewable energy source on the planet. Bioenergy, including traditional biomass use, generated around 12% of total final energy consumption in 2018. Modern bioenergy, on the other hand, accounted for over half of all renewable energy and provided 5.1% of total global final energy consumption [5,7]. Biomass energy will play a crucial role in meeting world energy growth over the coming years [8,9]. Bioenergy is expected to be the fastest-growing renewable energy source between 2018 and 2023, according to the International Energy Agency (with a projected growth rate of 30 percent).

As biomass energy becomes more commonly used, it has aroused the interest of numerous academics. A number of research have concentrated on the ecological consequences of biomass energy consumption [10–13], aside from research on investigating the influences of biomass energy use on economic development [14–17], human health [18–21], and human development [22–24]. The majority of these studies have used carbon emissions as a proxy for ecological quality. The key issue is that carbon emissions represent only a minor part of environmental damage [25]. This measure does not account for the overall effect of human actions on the environment. The ecological footprint, established by Wackernagel and Rees [26], is a more robust metric than carbon emissions [27,28]. According to the Global Footprint Network, the Ecological Footprint is the only metric that measures “how much nature we have and how much nature we use” [29]. Furthermore, the ecological footprint may account for both direct and indirect effects of human activity on the atmosphere [30]. As a result, the ecological footprint might be a good metric to use instead of carbon emissions when evaluating ecological efficiency.

The ecological footprint is a term that has recently increased in prominence and is now widely used in environmental studies [31–37]. However, only a few empirical studies [12,38,39] have looked into the connection between biomass energy and environmental footprint. This relationship has been the subject of debate in previous empirical studies. The literature has highlighted both the positive and negative effects of biomass energy use on environment. More precisely, biomass energy use is environmentally friendly, according to one group of researchers, because it reduces greenhouse gas emissions [40], CO2 emissions [10,41–44], and the ecological footprint [38]. Another party [12,13,45,46], on the other hand, has argued that biomass energy raises carbon emissions, which is bad for the atmosphere. Therefore, this study investigates the association between biomass energy consumption and ecological footprint in BRICS nations, taking into account the role of gross domestic product (GDP), natural resources, and globalization. We use different econometric techniques in this study, including cross sectional augmented IPS (CIPS) unit root tests, a Westerlund cointegration test, and AMG long-run estimation approach. These methods help account for cross-sectional dependency in panel data analysis and provide more accurate performance.

2. MODEL AND DATA

2.1 Econometric model

Based on the literature review and previous studies [12,47,48], we adopt the following model to explore the relationship between biomass energy use and ecological footprint, using economic growth (GDP), natural resources, and globalization as control variables:

$$EF_{it} = f\left(BIO_{it}, GDP_{it}, NR_{it}, GI_{it}\right) \qquad \text{(Eq.1)}$$

In equation (Eq.1), EF represents for ecological footprint, BIO stands for biomass energy consumption, GDP stands for economic growth, NR indicates for natural resources, and GI denotes for globalization index. A simple multivariate structure is applied to discover the relationship among all considered variables. Simultaneously, variables are converted in the form of natural logarithm to reduce dispersion and flat the data. The log-linear structure of the model is expressed in equation (Eq.2).

$$\ln(EF)_{it} = \alpha + \beta \ln(BIO)_{it} + \delta_1 \ln(GDP)_{it} + \delta_2 \ln(NR)_{it} + \delta_3 \ln(GI)_{it} + \varepsilon_{it} \qquad \text{(Eq.2)}$$

Where i (=1……, N), t (=1……, T) indicate the nations and time respectively. $\beta, \delta_1, \delta_2 \; and \; \delta_3$ denote the coefficients of biomass energy, economic growth, natural resources and globalization index, respectively. ε_{it} is the random error and α indicates for intercept. The coefficient β, which calculates the partial effect of biomass energy consumption on ecological footprint, is the main object of our study.

2.2 Data

We use an annual dataset from 1990 to 2017 to examine the connection between biomass energy use and the ecological footprint in the BRICS nations. Data of ecological footprint (gha per capita) have been extracted from the Global Footprint Network [29]. Biomass energy consumpitn (tons per capita) is derived from the UN Environment's Global Material Flows Database [49]. Globalization data is extracted from the KOF Globalization Index [50]. Rest of the control variables are collected from World Development Indicator (WDI), World Bank [51].

2.3 Methodology

`Following the 4-step procedure, advanced econometric methods are applied to calculate the long-run coefficient of Eq (1) in order to determine the influence of biomass energy use on ecological footprint. First, the cross-sectional dependency is confirmed by employing the Breusch and Pagan LM test and the Pesaran CD test. Second, the the stationarity assumptions are investigated using CIPS panel unit root test. If the non-stationarity is verified, the third step uses Westerlund approach to see if there are any cointegrating relationships exists or not. Finally, after confirming that the variables are cointegrated, parameters are calculated using second-generation augmented mean group estimation technique (AMG).

2.3.1 Cross-sectional dependence tests

One of the flaws of preceding analytical approaches is the presumption of cross-sectional independence. If cross-sectional dependency is not addressed in the panel data, the study results from such methods can be biased. To address this problem, we conducted cross-sectional dependence tests at the start of the research. LM [52] and CD test [53] are applied to determine the cross-sectional dependence in the current research.

The following equation is used to calculate LM test statistic:

$$LM^{BP} = T\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{r}_{ij}^2 \qquad \text{(Eq.3)}$$

For the sufficiently large number of T, the LM test is ineffective. Pesaran proposes the following CD test as an alternative to solving this problem:

$$CD^P = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{r}_{ij}^2\right) \qquad \text{(Eq.4)}$$

In Eq.(3) and Eq.(4) $\hat{r}_{ij}^2$ reveals the cross-section correlation of the error.

2.3.2 Panel unit root test and cointegration test

Non-stationary variables might lead to erroneous regression findings and hence it is important to verify the stationary properties of the considered variables. The existence of cross-sectional dependency across countries was investigated using Pesaran's [54] cross-sectional augmented IPS (CIPS) test. Before estimating the long-run coefficient, a test of cointegration can be employed to discover the long-run connection within the variables if the series has unit root.We used the Westerlund [55] method at this stage, which address the issue of cross-sectional dependency, instead of the cointegration test of Pedroni [56,57] and Kao [58].

2.3.3 Estimation of long-run coefficients

After confirming the existence of cointegration among the variables, the estimation of the long-run coefficient can be computed. Coefficients can be calculated employing augmented mean group (AMG) [59] estimation technique in the existence of cross-sectional dependency and slope heterogeneity.

The AMG estimator is calculated in 2 phases. First, it uses first difference OLS to combine the unobserved common factor with the time dummies in the following equation:

$$\Delta Y_{it} = \alpha_i + \beta_i \Delta X_{it} + \phi_i f_t + \sum_{t=2}^{T}\theta_t DUMMY_t + \varepsilon_{it} \qquad \text{(Eq.5)}$$

where Δ uses as a difference operator, α_i indicates the constant, X_{it} and Y_{it} are the predictor and outcome variables respectively, β_i represents the slope of every cross-section, and ε_{it} represents random error.

Second, the cross-section model parameters are averaged over the panel.

$$AMG = \frac{1}{N}\sum_{i=1}^{N}\tilde{\beta}_i \qquad \text{(Eq.6)}$$

3. RESULTS AND DISCUSSION

The findings for the entire sample are presented in this section. Table 1 displays the cross-section dependency results. Based on the related p-values of LM and CD test statistics, we may reject the null hypothesis of cross-section independence for ecological footprint, biomass energy use, economic growth, natural resources, and globalization index. As a result, all variables in this study have cross-section dependence.

Table 1. Cross-sectional dependence test.

Variables	LM		CD	
	Statistic	p-value	Statistic	p-value
lnEF	47.71	0.000	3.15	0.000
lnBIO	61.31	0.000	5.55	0.000
lnGDP	228.29	0.000	15.05	0.000
lnNR	127.37	0.000	10.92	0.000
lnGI	269.96	0.000	16.43	0.000

It is necessary to determine if data are unit-roots before evaluating cointegration. CIPS was used in this analysis to detect the presence of unit roots in the variables. Table 2 provides a summary of the test findings. As a result of the CIPS test, all five variables appear to be I (1).

Table 2. Panel unit root test.

Variables	CIPS test	
	Level	1st difference
lnEF	-0.069	-4.739^{***}
lnBIO	-2.310^{*}	-4.519^{***}
lnGDP	-2.495^{*}	-3.226^{***}
lnNR	-1.395	-4.086^{***}
lnGI	-2.544^{*}	-2.293^{***}

Significance level (* 10% ** 5%, *** 1%).

Westerlund panel cointegration tests were used to find the long-run connection among variables in Eq. (1). The null hypothesis in this test is that the panel has no cointegration. Table 3 shows that there is a long-run relationship among the considered variables, rejecting the null hypothesis at the 5% level.

Table 3. Panel cointegration tests.

Westerlund (2005)	t-statistic	p-value
Variance ratio	-1.5354	0.0423

After establishing a long-run association among variables, the coefficients in Eq (1). were estimated using augmented mean group (AMG) technique. Table 4 shows the estimated coefficients and p-values for the related predictor variables with ecological footprint as the regressed variable (lnEF)

Table 4. AMG long run coefficient estimation.

Variables	Coefficient	Std. error of coefficient	p-value
lnBIO	0.1358	0.1224	0.0268
lnGDP	0.7044	0.0888	0.000
lnNR	0.0193	0.0249	0.438
lnGI	-0.1737	0.0509	0.001

The influence of biomass energy usage on the environment is a major concern. Results in Table 4 suggest that biomass energy use have a statistically significant positive influence on ecological footprint; for instance, a 1 percent upsurge in biomass energy consumption rises ecological footprint by 0.14 percent on average for the BRICS countries. This result backs up claims and findings from a large body of research that biomass energy consumption degrades environment. However, increasing the efficiency of biomass energy production will support to shrink costs, promoting the usage of biomass energy as a substitute for fossil fuels. As a result, a major growth in biomass energy production might help reduce reliance on fossil fuels while also addressing ecological issues [60]. Furthermore, food crops and hydrocarbon-rich plants are the primary sources of biomass for energy generation [61]. The expansion of these sources absorbs CO_2, which is the main cause of climate change. These advantages, however, are insufficient to compensate for the negative effects of biomass energy extraction on ecologies in the BRICS nations. Soil abrasion, nutrient depletion, deforestation, water amount and quality deprivation, and land rivalry are all problems that may arise from the cultivation of energy crops. Furthermore, biomass harvesting and combustion may have negative environmental implications. Although the environmental effects of biomass energy use in the BRICS nations are still being debated [11,62,63], our empirical findings are an effort to draw the attention of BRICS policymakers to the detrimental effects of biomass energy consumption. Figure 1 depicts long-run relationship and their directions.

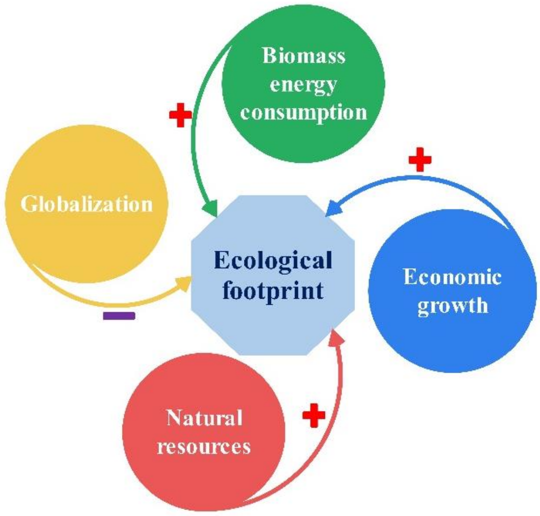

Fig 1. Graphic long-run relationships with ecological footprint.

4. CONCLUSIONS AND POLICY IMPLICATIONS

This study investigates the connection between biomass energy use and ecological footprint in BRICS nations from 1990 to 2017, taking natural resources and globalization into account. In this paper we employed second generation unit root tests, Westerlund cointegration approach and AMG estimator to diagnose the causal relationship between underlying variables. The findings suggest that biomass energy use has a positive influence on the ecological footprint. On the contrary, globalization reduce the ecological footprint for the BRICS nations.

Some policy guidelines for BRICS countries are proposed based on these empirical findings. Biomass energy can be a driver of economic development in these countries [62,64], but it devastates the environment. As a result, reducing biomass energy extraction could help BRICS countries improve environmental quality. Policymakers in these nations can focus on other renewable energy sources, such as wind and solar, which have less adverse environmental repercussions.

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