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RESEARCH PAPER

The Impact of Biomass Energy Consumption on CO_2 Emission and Ecological Footprint: The Evidence from BRICS Countries

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Abstract

In this study, it is aimed to analyze the effect of biomass energy consumption on environmental degradation for BRICS (Brazil, Russia, India, China, and South Africa) countries. For that purpose, the data of CO_2 emission values, ecological footprint and its components, "cropland, grazing land, forest land, fishing ground, built-up land, and carbon footprint" from 1992 to 2018 are used as criteria of environmental degradation. The diversity of the variables used regarding environmental degradation is important in terms of evaluating the effect of biomass energy consumption in detail. Pedroni and Kao Co-integration tests and FMOLS and DOLS analyses are used to estimate long-term correlation coefficients. With these analyses used, it was aimed to make more reliable estimations with the number of observations in the sample analyzed. According to the result of this study, biomass energy consumption increases ecological footprint values but decreases CO_2 emission in BRICS countries. In addition, economic growth increases ecological footprint and CO_2 emission; however, urbanization decreases them in BRICS countries.

Article Highlights

- **CO_2 and its six sub-components (cropland, grazing land, forest land, fishing ground, built-up land, and carbon footprint) and ecological footprint are used as environmental degradation criteria in all analyses.**
- **Biomass energy consumption increases ecological footprint in BRICS countries.**
- **Biomass energy consumption decreases CO_2 emission in BRICS countries.**
- **Economic growth increases ecological footprint and CO_2 emission.**
- **Urbanization decreases ecological footprint and CO_2 emission in BRICS countries.**

Keywords BRICS · Ecological footprint · Biomass energy consumption · Environmental degradation · Urbanization

Introduction

Adequate and proper use of energy resources is essential for sustainable development. Economies can get their needed energy from renewable and non-renewable resources. However, non-renewable energy resources (fossil and nuclear) have limited reserves in nature. They have also some disadvantages due to the CO_2 which they emit to the environment while being converted into energies such as electricity and heat. However, renewable energy resources (hydraulic, solar, wind, geothermal, biomass, wave tide, and hydrogen) have significant advantages since they are sustainable and environment friendly. It is also accepted that an increase in renewable energy consumption will decrease CO_2 emission. Therefore, renewable energy consumption has become one of the best alternative strategies for sustainable development (Liu et al. 2020). Therefore, the interest in clean energy resources for environmental sustainability is very high all over the world (Dong et al. 2017). Numerous empirical studies indicate that renewable energy consumption is negatively correlated with carbon emissions and plays a positive role in improving environmental quality (Sadorsky 2009; (Sadorsky 2009; Apergis et al. 2010; Pao and Fu 2013; Mert and Bölük 2016; Bilgili et al. 2016; Destek 2016; Armeanu

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2017; Dong et al. 2017; Ito 2017; Inglesi-Lotz and Dogan 2018; REN21 2018; Mert et al. 2019; Damette and Marques 2019; Zafar et al. 2019; Acheampong et al. 2019; Alola et al. 2019; Nguyen and Kakinaka 2019; Sharif et al. 2019; Bourcet 2020).

Biomass energy, one of the significant renewable energy resources, is essential in terms of energy and environmental sustainability. Biomass energy is an energy resource that obtained as a result of the use of biomass wastes by burning or undergoing different processes. This energy sources are specially grown plants such as corn, wheat, trees, droppings, industrial wastes, and all organic garbage (fruit and vegetable wastes) of houses. By burning these materials, environment gets cleaner, and energy resource such as electricity and heat can be produced. In general, biomass energy consumption has significant advantages in decreasing greenhouse gas emissions caused by the use of fossil fuels, degradation of forests, and industrial processes. Particularly, biomass energy consumption has an increasing interest because it is environmentally friendly, can be found everywhere and in abundance, and converted into energies such as electricity and heat. However, gases such as CO_2, N_2O and CH_4 that may cause environmental degradation can be released during biomass burning. While biomass energy consumption decreases CO_2 emission according to some studies (Bilgili et al. 2016; Shahbaz et al. 2017; Dogan and Inglesi-Lotz 2017), it increases CO_2 emission just like non-renewable energy resources, according to some studies (Solarin et al. 2018; Shahbaz et al. 2018). For that reason, knowing the effect of biomass energy consumption on environmental degradation is highly important for energy and environmental sustainability.

In this study, the effect of biomass energy consumption on environmental degradation in BRICS (Brazil, Russia, India, China, and South Africa) countries is examined. BRICS countries are among the fastest growing economies in the world, according to the 2018 Global Status Report. While China and India are the leading economies in production, Brazil and Russia have rich resources such as oil and natural gas. BRICS countries are also rich in renewable energy resources (Kobayashi-Hillary 2007). In BRICS countries, biomass energy consumption consisting of wood, nonwood and waste components constitutes 36.8% of the total energy consumption in these countries (Bildirici 2014; Shahbaz et al. 2016). The most important reason for this is that BRICS countries prefer biomass energy for sustainable development because biomass energy is fast and easy to obtain (Shahbaz et al. 2016, 2018). In addition, leaders of BRICS countries emphasized in the meeting in Xiamen in September 2017 that they needed to improve environment-friendly technologies and urban environmental sustainability and develop the cooperation of member countries on environmental issues. At that point, this study aims to evaluate the effect of biomass energy consumption on environmental degradation to ensure sustainable development and help to determine the policies that should be implemented to achieve this goal.

It is aimed to contribute to the literature at two points with this study. Accordingly, the first contribution pertains to the degradation criteria included in the study. CO_2 emission is commonly used in the literature as an environmental degradation criterion (Sarkodie and Ozturk 2020; Shahbaz et al. 2019; Kang et al. 2016). CO_2 emission as an environmental degradation criterion can be valid in some cases but not in all cases (Ulucak and Lin 2017). Therefore, CO_2 and its six sub-components (cropland, grazing land, forest land, fishing ground, built-up land, and carbon footprint) and ecological footprint are used as environmental degradation criteria in all analyses. The use of ecological footprint and its subcomponents (cropland, grazing land, forest land, fishing ground, built-up land, and carbon footprint) as a comprehensive environmental degradation is essential for detailing findings in this study. Another significant contribution is to include urbanization in the model as a descriptive variable.

Therefore, the effect of urbanization on the selected environmental degradation criteria is also examined in the study. Because urbanization may cause more energy consumption, and also it is a factor that may cause more biomass waste. This may cause more greenhouse gas effects and an increase in environmental degradation. However, people in heavily populated urban areas are also more inclined to prefer clean energy resources that may cause less environmental degradation. For that reason, urbanization becomes a factor that sometimes increases environmental degradation (Mahmood et al. 2020; Ahmed et al. 2020a; Younis et al. 2021; Nathaniel et al. 2021a) but sometimes decreases environmental degradation (Ulucak and Khan 2020; Ahmed et al. 2020b). The purpose of this study is also to examine the effect of urbanization on environmental degradation. To test the validity of the EKC hypothesis that examines the hypothetical relationship between the deterioration of environmental conditions and the level of per capita income, the square of GDP was also included in the study. To test the validity of the EKC hypothesis, the square of GDP was also included in the study. While some studies state that economic growth increase the environmental quality (Tamazian et al. 2009; Anser et al. 2021), some state that economic growth accelerates environmental degradation (Rahman 2020; Ahmed et al. 2020a, b; Nathaniel et al. 2021a; Muhammad et al. 2021).

Another significant contribution is the literature on environmental degradation in BRICS countries because the literature that examines biomass energy consumption and environmental degradation for BRICS countries is quite rare. Because BRICS countries are under high pressure on environmental degradation as well as being fast-growing economies. For that reason, BRICS countries also have to minimize environmental degradation while keeping their increasing economic growth rate. For that reason, biomass energy consumption as a clean energy resource in BRICS countries has an increasing interest because it is readily available and producible. The results of this study are also significant because they can provide information that can help policymakers decide on biomass energy consumption for sustainable development. It is thought that this study will contribute to the literature to evaluate the effect of biomass energy consumption in BRICS countries on CO_2 and ecological footprint and cropland, grazing land, forest land, fishing ground, built-up land, and carbon footprints included in the study as an environmental degradation criterion.

This study consists of five parts. After the introduction, it follows literature, data set and methodology, empirical findings and as a final evaluation.

Literature Review

Environmental degradation is one of the crucial issues of the energy economy. The use of renewable energy resources for a sustainable environment and energy is essential especially for decreasing environmental degradation. The literature review in this study has two parts as the literature examining the relationship between renewable energy consumption and environmental degradation and the literature examining the relationship between renewable energy consumption and environmental degradation for BRICS countries.

Literature Review for Relationship Between Renewable Energy Consumption and Environmental Degradation

CO_2 emission is commonly used in the literature as an environmental degradation criterion. However, the ecological footprint is also used in recent studies (Charfeddine, 2017; Bello et al. 2018). In this study, eight different environmental degradation criteria for CO_2 emission and ecological footprint are also included. Accordingly, some studies examining the relationship between renewable energy consumption and environmental degradation are as in Table 1.

Studies examining the correlation between renewable energy consumption and environmental degradation criteria obtained different results in the literature. Accordingly, empirical results indicating that renewable energy consumption decreases environmental degradation (Menyah and Wolde-Rufael 2010; Apergis et al. 2010; Shafiei and Salim 2014; Bilgili et al. 2016; Paramati et al. 2017; Sharif et al. 2019; Sharif et al. 2020a, b; Rauf et al. 2020; Destek 2016; Pham et al. 2020; Khan et al. 2020; Destek and Sinha 2020; Khan et al. 2021), there is no correlation between renewable energy consumption and environmental degradation (Menyah and Wolde-Rufael, 2010; Saidi and Mbarek 2016; Bento and Moutinho 2016; Cherni and Jouini, 2017; Jebli and Youssef 2017; Liu et al. 2017a; Chen et al. 2019; Alola et al. 2019), renewable energy consumption increases environmental degradation (Farhani and Shahbaz 2014; Apergis and Payne 2015; Khan et al. 2018; Yazdi and Beygi 2018,) or environmental degradation increases renewable energy consumption while renewable energy consumption decreases environmental degradation (Apergis et al. 2010; Dogan and Seker 2016; Waheed et al. 2018; Cai et al. 2018; Sharif et al. 2020a, b; Koengkan et al. 2020) were obtained.

Literature Review for Relationship Between Renewable Energy Consumption and Environmental Degradation in BRICS Countries

Examining the relationship between renewable energy consumption and environmental degradation in BRICS countries has been a focus of interest for researchers in recent years. Because BRICS countries aim appropriate environmental policies to meet their fast-growing economies and increasing energy needs with the lowest environmental degradation. Accordingly, some studies examining the correlation between renewable energy consumption and environmental degradation for BRICS countries are as in Table 2.

According to Table 2, increasing renewable energy consumption decreases environmental degradation in BRICS countries (Dong et al. 2017; Liu et al. 2017b; Bhat 2018; Baloch et al. 2019; Wang 2019; Chen et al. 2019; Nathaniel et al. 2021b; Shoukat et al. 2020; Ulucak and Khan 2020; Khattak et al. 2020; Liu et al. 2020; Akram et al. 2020; Muhammad et al. 2021; Nawaz et al. 2021; Younis et al. 2021; Pata 2021, Awosusi et al. 2022). However, Karmaker et al. (2021), Kongbuamai et al. (2021) and Dong et al. (2017) state that while renewable energy consumption decreases environmental degradation, environmental degradation increases renewable energy consumption.

Data and Methodology

Data

The effect of biomass energy consumption on environmental degradation in BRICS countries is examined in this study. For that purpose, ecological footprint and its components, “cropland, grazing land, forest land, fishing ground, built-up land and carbon footprint” and CO_2 emission values, were used as environmental degradation criteria. Other variables used in the study are biomass energy consumption, economic growth and urbanization. The data set for all variables include the period 1992–2018. GDP (gross domestic product), the economic growth data, the data set belonging

Table 1 Literature review for relationship between renewable energy consumption and environmental degradation

Author(s)	Period	Country	Methodology	Conclusion			
				There is no relationship between REC and ED	REC reduces ED	REC increases ED	REC decreases ED and ED increases REC
Menyah and Wolde-Rufael (2010)	1960–2007	USA	Toda-Yamamoto Granger non-causality	✓			
Apergis et al. (2010)	1984–2007	19 countries	ECM and Granger causality		✓		
Farhani and Shahbaz (2014)	1980–2009	10 MENA countries	Granger causality			✓	
Shafiei and Salim (2014)	1980–2011	OECD countries	VECM		✓		
Apergis and Payne (2015)	1980–2010	11 South American countries	Engle and Granger causality			✓	
Saidi and Mbarek (2016)	1990–2013	9 developed countries	Granger causality	✓			
Bento and Moutinho (2016)	1960–2011	Italy	TY Granger causality	✓			
Dogan and Seker (2016)	1980–2012	15 European Union	DOLS, Dumitrescu–Hurlin non-causality				✓
Bilgili et al. (2016)	1977–2010	17 OECD countries	DOLS and FMOLS		✓		
Cherni and Jouini (2017)	1990–2015	Tunisia	ARDL and Granger causality	✓			
Jebli and Youssef (2017)	1980–2011	North Africa countries	Granger causality	✓			
Liu et al. (2017a)	1970–2013	4 ASEAN countries	VECM	✓			
Paramati et al. (2017)	1990–2012	Next 11 countries	Dumitrescu–Hurlin panel causality		✓		
Khan et al. (2018)	1981–2015	Pakistan	TY Granger causality			✓	
Waheed et al. (2018)	1990–2014	Pakistan	VECM				✓
Yazdi and Beygi (2018)	1985–2015	25 African countries	Granger causality			✓	
Cai et al. (2018)	1965–2015	G7 Countries;	ARDL, Granger causality				✓
Sharif et al. (2019)	1990–2015	74 Different Countries	Westerlund (2007) cointegration, Pedroni cointegration, FMOLS, panel causality		✓		
Alola et al. (2019)	1997–2014	16 European Countries	PMG-ARDL		✓		
Chen et al. (2019)	1980–2014	China	ARDL and VECM Granger causality		✓		
Sharif et al. (2020a)	1990–2017	Top-10 Polluted Countries	Quantile-on-quantile regression approach				✓
Sharif et al. (2020b)	1965–2017	Turkey	Quintile ARDL approach		✓		
Rauf et al. (2020)	1981–2016	65 Belt-and-Road Countries	FMOLS AND DOLS		✓		
Destek (2016)	1980–2014	OECD Countries	MG, FMOLS, and DOLS		✓		

Table 1 (continued)

Author(s)	Period	Country	Methodology	Conclusion			
				There is no relationship between REC and ED	REC reduces ED	REC increases ED	REC decreases ED and ED increases REC
Pham et al. (2020)	1990–2014	28 European Countries	PVAR, FMOLS		✓		
Khan et al. (2020)	2001–2018	Nordic Counties	CIPS unit root test and cross-sectional dependence		✓		
Koengkan et al. (2020)	1980–2014	Argentina, Brazil, Paraguay, Uruguay, and Venezuela	PVAR and Granger causality				✓
Khan et al. (2021)	1971–2016	USA	Cointegration analysis		✓		

REC renewable energy consumption, *ED* environmental degradation

to urbanization (urbanization measured as the proportion of the urban population to total population), and CO_2 emission series were obtained from WDI (world development indicators). Biomass energy data were obtained from the database of materialflows.net. The data set belonging to ecological footprint and its components were obtained from NFA (National Footprint Accounts).

The changes in the CO_2 emission, ecological footprint and biomass energy consumption values of the BRICS countries are as in Figs. 1, 2 and 3.

According to Fig. 1, Russia has the highest CO_2 emission value, while India has the lowest. The CO_2 emission change rate in China is the highest. CO_2 emission values in South Africa, on the other hand, tend to decrease in general, although they show an increasing trend from time to time. In Fig. 2, ecological footprint values, which is another environmental degradation criterion, are included.

According to Fig. 2, the ecological footprint of Russia is the highest, while it is the lowest for India. The country with the fastest increasing ecological footprint is China. The Ecological footprint of South Africa also tends to increase in general. In Fig. 3, the biomass energy consumption values of the BRICS countries are included.

Figure 3 shows the changes in biomass energy consumption. According to Fig. 3, biomass consumption in the BRICS countries shows a fluctuating course. While the biggest increases and decreases are in Russia, biomass consumption in South Africa increased significantly in periods such as 1995 and 2016; It also reduced its biomass consumption in 1994, 2000 and 2014. Descriptive statistical values for all variables used in this study are as in Table 3.

Descriptive statistical values belonging to ecological footprint and its subcomponents, CO_2 emission, biomass energy consumption, GDP and urbanization for BRICS countries are indicated in Table 3. According to Table 3, carbon footprint has the highest average value, and built-up footprint has the lowest average value. In addition, all variables except for urbanization have a positive skewness value, and it is seen that the series are right-skewed in the examined period. Urbanization has a negative skewness value, and it is seen that the series are left-skewed. Kurtosis values are positive, and all series show leptokurtic features. All variables except for ecological footprint among the variables used in the study do not have normal distribution characteristics. However, the ecological footprint has a normal distribution characteristic.

The effect of biomass energy consumption on environmental degradation in BRICS countries is analyzed in this study through panel co-integration tests. The analysis of cross sections of time series is more efficient than individual time series, particularly in the case of short time series (Nguyen and Kakinaka 2019). First of all, stationarity analysis, then panel co-integration analyses were carried out in this study. Then long-term correlation coefficients were estimated through FMOLS and DOLS analyses.

Methodology

While the effect of biomass energy consumption on environmental degradation criteria was examined, it was based on Dietz and Rosa (1997)'s stochastic ımpacts by regression on population, affluence and technology (STIRPAT) model. This basic STIRPAT model is as Eq. 1:

$$I_t = \beta_0 P_t^{\beta_1} A_t^{\beta_2} T_t^{\beta_3} \mu_T, \quad (1)$$

I in Eq. 1 is the criterion of environmental degradation. P, A and T represent population, affluence and technology, respectively. μ is the random error term. Gross domestic product (GDP) is used to measure affluence-A in this model.

Table 2 Literature review for relationship between renewable energy consumption and environmental degradation in BRICS countries

Author(s)	Period	Methodology	Concluson			
			There is no relationship between REC and ED	REC reduces ED	REC increases ED	REC decreases ED and ED increases REC
Dong et al. (2017)	1985–2016	Granger causality				✓
Liu et al. (2017b)	1992–2013	VECM		✓		
Bhat (2018)	1992–2016	Panel cointegration test		✓		
Baloch et al. (2019)	1990–2015	AMG panel data estimation method		✓		
Wang (2019)	1992–2013	GMM		✓		
Khattak et al. (2020)	1980–2016	CCEMG technique (1 = Russia, India, China)		✓1		
Liu et al. (2020)	1999–2014	3SLS model		✓		
Ulucak and Khan (2020)	1996–2016	Cointegration, FMOLS, DOLS		✓		
Akram et al. (2020)	1990–2014	Nonlinear panel autoregressive distributed lag model		✓		
Wolde-Rufael and Weldemeskel (2020)	1993–2014	PMG-ARDL		✓		
Kongbuamai et al. (2021)	1995–2016	DSUR method, Dumitrescu and Hurlin panel causality tests				✓
Nathaniel et al. (2021b)	1992–2016	Coinegration and FMOLS, DOLS		✓		
Muhammad et al. (2021)	1991–2018	Dynamic fixed effect model, GMM, and system GMM estimators		✓		
Nawaz et al. (2021)	1980–2016	QARDL		✓		
Younis et al. (2021)	1993–2018	GMM		✓		
Pata (2021)	1971–2016	Fourier cointegration, causality tests (1 = Russia, India, 2 = Brazil, China)	✓1	✓2		
Karmaker et al. (2021)	1990–2017	BRICS	Cointegration analysis			✓
Awosusi et al. (2022)	1992–2018	BRICS	FMOLS, and DOLS, FE-OLS		✓	

REC renewable energy consumption, *ED* environmental degradation

The concept of T in this model can be adapted according to researcher's field of interest. Biomass energy consumption values were used in this study. In addition, urbanization was used as a demographic variable. The square of the GDP was added into the model in the study to test the EKC hypothesis. CO_2 emission is used in conventional practices as an environmental degradation criterion (for *I*) (Bello et al. 2018). However, ecological footprint and its components, "cropland, grazing land, forest land, fishing ground, built-up land, and carbon footprint" and CO_2 emission, are used in this study as environmental degradation criteria. Accordingly, Eq. 2 is obtained when the study model of Solarin et al. (2017) is revised for this study:

$$i_t = \beta_1 y_t^{\beta_2} (y^2)_t^{\beta_3} \text{bio}_t^{\beta_4} ub_t^{\beta_5} \mu_T. \quad (2)$$

According to Eq. 2, real GDP per capita and its square are represented by y and y^2 while the added variables biomass energy consumption per capita and urbanization are, respectively, represented by bio and ub. Taking the logs, the model is linearized as Eq. 3:

$$\ln i_t = \beta_0 + \beta_2 \ln y_t + \beta_3 \ln(y^2)_t + \beta_4 \ln \text{bio}_t + \beta_5 \ln ub_t + \mu_t. \quad (3)$$

Models for each environmental degradation criterion are expressed as between Eqs. 4,…10 and 11 when Eq. 3 is revised:

$$\text{lnbuiltup} f_t = \delta_0 + \delta_2 \ln y_t + \delta_3 \ln(y^2)_t + \delta_4 \ln \text{bio}_t + \delta_5 \ln ub_t + \varepsilon_t, \quad (4)$$

$$\ln cf_t = \delta_0 + \delta_2 \ln y_t + \delta_3 \ln(y^2)_t + \delta_4 \ln \text{bio}_t + \delta_5 \ln ub_t + \varepsilon_t, \quad (5)$$

$$\ln \text{crop} f_t = \delta_0 + \delta_2 \ln y_t + \delta_3 \ln(y^2)_t + \delta_4 \ln \text{bio}_t + \delta_5 \ln ub_t + \varepsilon_t, \quad (6)$$

$$\ln \text{fishing} f_t = \delta_0 + \delta_2 \ln y_t + \delta_3 \ln(y^2)_t + \delta_4 \ln \text{bio}_t + \delta_5 \ln ub_t + \varepsilon_t, \quad (7)$$

$$\ln \text{forest} f_t = \delta_0 + \delta_2 \ln y_t + \delta_3 \ln(y^2)_t + \delta_4 \ln \text{bio}_t + \delta_5 \ln ub_t + \varepsilon_t, \quad (8)$$

$$\ln \text{grazing} f_t = \delta_0 + \delta_2 \ln y_t + \delta_3 \ln(y^2)_t + \delta_4 \ln \text{bio}_t + \delta_5 \ln ub_t + \varepsilon_t, \quad (9)$$

$$\ln ef_t = \alpha_0 + \alpha_2 \ln y_t + \alpha_3 \ln(y^2)_t + \alpha_4 \ln \text{bio}_t + \alpha_5 \ln ub_t + \mu_t, \quad (10)$$

$$\ln CO_{2t} = \partial_0 + \partial_2 \ln y_t + \partial_3 \ln(y^2)_t + \partial_4 \ln \text{bio}_t + \partial_5 \ln ub_t + \omega_t. \quad (11)$$

Fig. 1 CO_2 emission change for BRICS countries

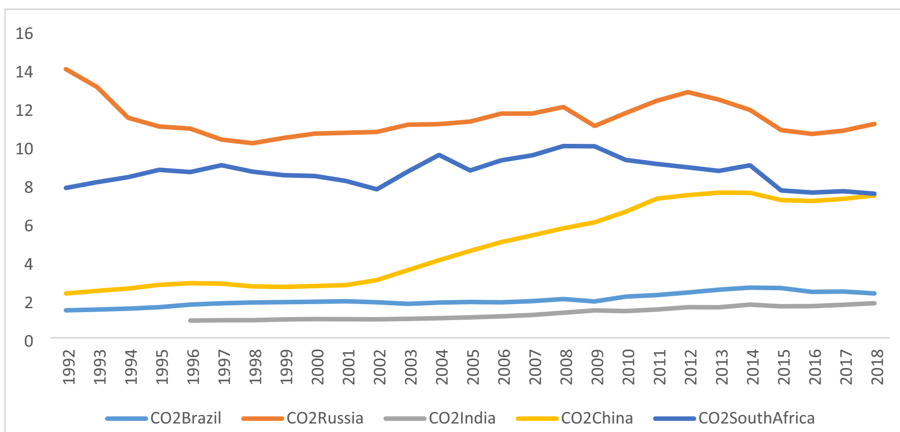
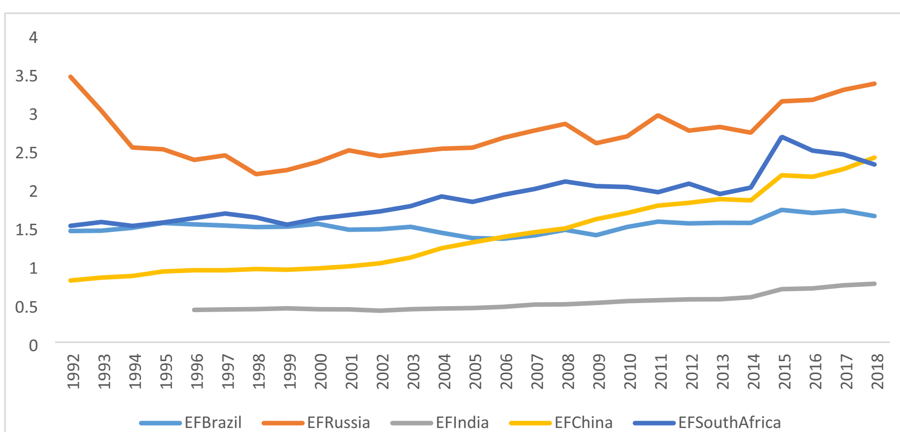


Fig. 2 Ecological footprint (EF) values for BRICS countries



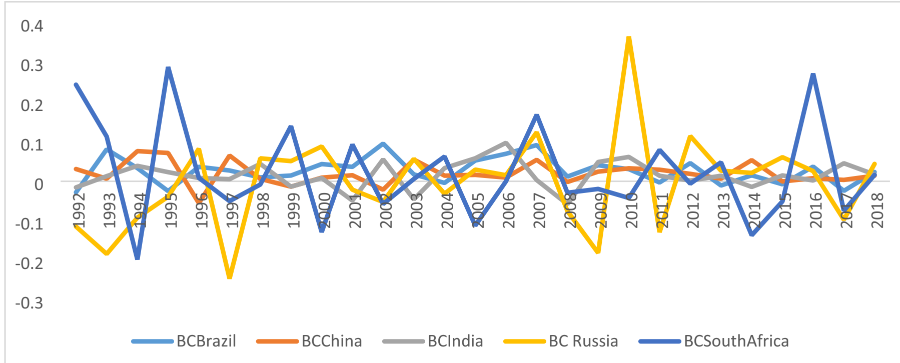


Fig. 3 Biomass energy consumption change (BC) for BRICS countries

In Eqs. 4, 5, 6, 7, 8, 9, 10, 11, it is represented by the eight measures of environmental degradation adopted in this study namely lnbuiltup f_t, lncf_t lncrop f_t, lnfishing f_t, lnforest f_t, lngrazing f_t, ln ef_t, and lnCO $_{2t}$ which are ln ef_t, lncrop f_t, lngrazing f_t, lnforest f_t, lnfishing f_t, lnbuiltup f_t, lncf_t and lnCO_{2t} are, respectively, the natural logs of per capita ecological footprint and its subcomponents "cropland, grazing land, forest land, fishing ground, builtup land, and carbon footprint", lnCO_{2t} the natural log of CO_2 emission per capita. lny_t and ln$(y^2)_t$ are the are the natural logs of real GDP per capita and its square. lnbio_t is the natural log of biomass energy consumption while ln ub_t stands for urbanization, μ_t , ε_t and ω_t are the different random error terms, respectively, for equations with 3, 4, 5. To validate the EKC hypothesis, it is required $\alpha_2, \delta_2, \partial_2 > 0$; and $\alpha_3, \delta_3, \partial_3 < 0$. The biomass energy consumption is expected to reduce environmental degradation. So it is required that $\alpha_4, \delta_4, \partial_4 < 0$. The impact of urbanization on the environment can be positive or negative. So it is expected $\alpha_5, \delta_5, \partial_5 < 0$; can be > 0 or < 0.

The stationarity of variables used should be initially analyzed in this study because the analyses performed with non-stationary data may give erroneous results. In this study Levin et al. (2002), Im et al. (2003), Fisher ADF and Fisher-PP stationarity tests were used to test the stationarity of variables. Pedroni (2004) co-integration test and Kao (1999) panel co-integration test were used to analyze the long-term correlation among the series. However, the long-term relationship coefficients were estimated using FMOLS and DOLS.

In the Pedroni panel cointegration analysis, seven different cointegration tests are used to cover four within cross-sectional effects and three between cross-sectional effects in the panel (Asteriou and Hall 2007). First, in the "within" section, the pooled panel v-statistic, panel rho-statistic, panel PP-statistic, and panel ADF-statistic values represent a variance type of statistic. Second, the statistics are similar to Phillips Peron (PP) (rho) statistics. Third, the statistics are similar to PP (t) statistics. Fourth, the statistics are parametric statistics similar to ADF (t) statistics. While the Group rho-statistic test in the "between" category is similar to the PP (rho) statistics, the group PP-statistic are group ADF-statistic, which are similar to PP (t) and ADF (t) statistics (Güvenek and Alptekin 2010). If the calculated statistics are larger than the critical values, a long-term cointegration relationship exists between the variables involved in the analysis. Kao panel kointegration and Kao tests are based on Engle and Granger (1987) two-step (residual-based) cointegration tests. To serve as a robustness check to that of Pedroni, i conducted another test especially Kao panel cointegration.

It is usually for Panel FMOLS and DOLS methods developed by Pedroni (2001), after determining the co-integration relationship. It is to estimate the long-term parameters for the relationship between the variables. However, long-term coefficients between the variables with a long-term relationship were estimated using the FMOLS method and DOLS methods. It is aimed to increase the validity of the results obtained using these two estimators to estimate the long-term coefficients.

Empirical Results

Stationary Results

Unit root test results belonging to the variables used in the study are as in Table 4.

According to Table 4, different stationarity test results indicate that the analyzed series become stationary when the first difference is taken. The long-term correlation of stabilized environmental degradation criteria with GDP, biomass energy consumption and urbanization are the other variables, was initially analyzed with the Pedroni panel co-integration test. Accordingly, Pedroni co-integration test results are in Table 5.

According to Pedroni cointegration test results in Table 5, there is a long-term correlation between ecological footprint and GDP, biomass energy consumption and urbanization. For built-up land, carbon, cropland, fishing ground and

Table 3 Descriptive statistic for variables

	Built up land footprint	Carbon footprint	Cropland footprint	Fishing grounds footprint	Forestland footprint	Grazing land footprint	Ecological footprint	Co_2 emissions	Biomass energy consumption	GDP	Urbanization
Mean	0,027	0,860	0,263	0,041	0,176	0,149	1,517	5,532	4,021	5670,486	56,556
Median	0,019	0,658	0,232	0,037	0,177	0,069	1,516	3,524	3,220	5928,959	58,446
Maximum	0,059	2,208	0,628	0,101	0,432	0,568	3,449	13,979	11,990	11,993,49	85,492
Minimum	0,007	0,126	0,145	0,006	0,064	0,003	0,401	0,768	1,730	595,013	25,984
Std. dev	0,014	0,612	0,097	0,028	0,095	0,173	0,740	4,142	2,653	3583,583	20,262
Skewness	0,712	0,424	1,070	0,505	0,338	1,390	0,181	0,340	1,604	0,012	−0,190
Kurtosis	2,074	1,729	3,842	1,971	1,855	3,375	2,350	1,520	4,602	1,765	1,552
Jarque–Bera	13,835	11,192	25,382	9,971,818	8,473	37,736	2,650	61,641	7,306	11,959	10,742
Probability	0,000	0,003	0,000	0,006	0,014	0,000	0,265	0,000	0,025	0,002	0,004

forest pro footprints that are the sub-components of ecological footprint used as environmental degradation criteria, the long-term correlation with GDP, biomass energy consumption and urbanization is confirmed within-dimension and between-dimension test statistics. In other words, there is a long-term correlation between built-up land, carbon, cropland, fishing ground, forest pro footprint and GDP, biomass energy consumption and urbanization. However, according to Table 5, there is no long-term correlation between grazing land footprint and GDP, biomass consumption and urbanization. According to Table 5, there is a long-term correlation between GDP, biomass energy consumption and urbanization for CO_2 emission used as conventional environmental degradation criterion.

To reinforce the results of the Pedroni panel cointegration test, the results of the Kao panel cointegration test, in which the long-term relationship of each environmental degradation criterion with GDP, biomass energy consumption and urbanization are examined, are as in Table 6.

According to Table 6, "There is no correlation of co-integration", the null hypothesis of the Kao panel co-integration test is rejected for all environmental degradation criteria. Accordingly, the existence of a long-term relationship between biomass energy consumption and urbanization is supported for ecological footprint and its sub-components built-up, carbon, cropland, fishing ground, grazing land, forest pro footprints and CO_2 emission.

The long-term correlation coefficients between each environmental degradation and GDP, biomass energy consumption and urbanization were estimated with FMOLS and DOLS analyses. Accordingly, the long-term coefficients of each environmental degradation criterion with GDP, biomass energy consumption and urbanization for FMOLS and DOLS are as in Table 7.

According to FMOLS results in Table 7, the coefficient of GDP is positive (except for forest pro footprint) and statistically significant (except for carbon footprint) in all environmental degradation criteria. According to DOLS results, GDP is unfavourable for fishing ground and forest pro footprints and statistically significant only for forest pro footprint. It is positive and statistically significant (except for grazing land footprint) for all environmental degradation criteria. According to these results, economic growth is a factor that accelerates environmental degradation.

According to FMOLS results in Table 7, the coefficient of the square of GDP that EKC hypothesis is tested is positive and statistically significant for all environmental degradation criteria except for carbon footprint. According to DOLS results, GDP^2 is positive and statistically significant for all environmental degradation criteria; it is not statistically significant only for grazing land footprint. Therefore, the EKC hypothesis is not valid for BRICS countries.

Table 4 Results of unit root tests for variables

	Level				First difference			
	LLC	IPS	ADF—Fisher Chi-square	PP—Fisher Chi-square	LLC	IPS	ADF—Fisher Chi-square	PP—Fisher Chi-square
Built-up land footprint	0.229 (0.590)	1.422 (0.923)	5.130 (0.882)	14.561 (0.149)	−8.330 (0.000)***	−8.701 (0.000)***	80.075 (0.000)***	202.015 (0.000)***
Carbon footprint	2.027 (0.978)	2.949 (0.998)	4.327 (0.931)	7.174 (0.709)	−1.963 (0.025)**	−2.571 (0.005)***	25.644 (0.004)***	51.239 (0.000)***
Cropland footprint	1.886 (0.970)	−1.533 (0.063)	4.361 (0.930)	4.714 (0.909)	−8.872 (0.000)***	−9.127 (0.000)***	84.516 (0.000)***	363.420 (0.000)***
Fishing grounds footprint	1.299 (0.903)	−1.056 (0.146)	4.741 (0.908)	4.849 (0.901)	−6.658 (0.000)***	−2.523 (0.006)***	54.872 (0.000)***	97.479 (0.000)***
Forestland footprint	−0.545 (0.292)	−0.163 (0.435)	8.396 (0.590)	11.057 (0.353)	−5.492 (0.000)***	−5.781 (0.000)***	50.808 (0.000)***	70.267 (0.000)***
Grazing land footprint	0.391 (0.652)	0.722 (0.765)	7.272 (0.700)	7.557 (0.672)	−4.231 (0.000)***	−4.833 (0.000)***	41.632 (0.000)***	77.058 (0.000)***
Ecological footprint	1.048 (0.852)	1.685 (0.954)	6.876 (0.737)	11.153 (0.346)	−2.721 (0.003)***	−3.457 (0.000)***	32.141 (0.000)***	55.523 (0.000)***
CO_2 emissions	1.105 (0.865)	2.147 (0.984)	8.589 (0.572)	9.427 (0.492)	−2.839 (0.002)***	−3.013 (0.001)***	27.262 (0.002)***	42.635 (0.000)***
Biomass energy consumption	−0.020 (0.492)	−1.243 (0.107)	1.763 (0.998)	1.673 (0.998)	−8.244 (0.000)***	−8.222 (0.000)***	75.400 (0.000)***	302.533 (0.000)***
GDP	3.950 (1.000)	5.217 (1.000)	0.664 (1.000)	0.238 (1.000)	−1.496 (0.067)*	−1.375 (0.085)*	17.173 (0.071)*	26.887 (0.003)***
Urbanization	1.635 (0.949)	3.193 (0.999)	3.044 (0.980)	4.617 (0.915)	−5.540 (0.000)***	−2.746 (0.003)***	22.795 (0.012)**	22.024 (0.015)**

(1) Figures in the parenthesis indicate *p* values. *, **, and *** represent the 10%, 5%, and 1% significance levels, respectively

(1) Figures in the parenthesis indicate *p* values. *, **, and *** represent the 10%, 5%, and 1% significance levels, respectively

Table 5 Results of Pedroni panel cointegration for environmental degradation measures

Within-dimension	$\ln \text{builtup} f_t = \delta_0 + \delta_2 \ln y_t + \delta_3 \ln(y^2)_t + \delta_4 \ln \text{bio}_t + \delta_5 \ln ub_t + \varepsilon_t$				$\ln cf_t = \delta_0 + \delta_2 \ln y_t + \delta_3 \ln(y^2)_t + \delta_4 \ln \text{bio}_t + \delta_5 \ln ub_t + \varepsilon_t$				$\ln \text{crop} f_t = \delta_0 + \delta_2 \ln y_t + \delta_3 \ln(y^2)_t + \delta_4 \ln \text{bio}_t + \delta_5 \ln ub_t + \varepsilon_t$				$\ln \text{fishing} f_t = \delta_0 + \delta_2 \ln y_t + \delta_3 \ln(y^2)_t + \delta_4 \ln \text{bio}_t + \delta_5 \ln ub_t + \varepsilon_t \delta_5 \ln ub_t + \varepsilon_t$			
			Weighted				Weighted				Weighted				Weighted	
	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.
Panel v-statistic	−0.088	0.535	−1.306	0.904	−1.382	0.917	−0.821	0.794	−1.021	0.846	−1.761	0.961	2.406	0.008	1.180	0.119
Panel rho-statistic	−0.055	0.478	−0.816	0.207	0.914	0.820	0.768	0.779	−0.497	0.309	−0.367	0.357	−0.323	0.373	0.671	0.749
Panel PP-statistic	−3.099***	0.001	−5.816***	0.000	−1.553*	0.060	−1.486*	0.069	−4.010***	0.000	−7.313***	0.000	−2.436***	0.007	−1.018	0.154
Panel ADF-statistic	−3.411***	0.000	−5.888***	0.000	−1.381*	0.084	−1.054	0.146	−0.357***	0.000	−4.658***	0.000	−2.391***	0.008	−1.120	0.131
Between-dimension																
	Statistic	Prob.			Statistic	Prob.			Statistic	Prob.			Statistic	Prob.		
Group rho-statistic	−0.142	0.444			1.763	0.961			0.585	0.721			1.379	0.916		
Group PP-statistic	−9.482***	0.000			−1.180	0.119			−9.744***	0.000			−1.152	0.125		
Group ADF-statistic	−8.328***	0.000			−1.999**	0.023			−5.579***	0.000			−1.091	0.138		
Within-dimension	$\ln \text{forest} f_t = \delta_0 + \delta_2 \ln y_t + \delta_3 \ln (y^2)_t + \delta_4 \ln \text{bio}_t + \delta_5 \ln ub_t + \varepsilon_t$				$\ln \text{grazing} f_t = \delta_0 + \delta_2 \ln y_t + \delta_3 \ln (y^2)_t + \delta_4 \ln \text{bio}_t + \delta_5 \ln ub_t + \varepsilon_t$				$\ln ef_t = \alpha_0 + \alpha_2 \ln y_t + \alpha_3 ln (y^2)_t + \alpha_4 \ln \text{bio}_t + \alpha_5 \ln ub_t + \mu_t$				$\ln CO_{2t} = \partial_0 + \partial_2 \ln y_t + \partial_3 ln(y^2)_t + \partial_4 \ln \text{bio}_t + \partial_5 \ln ub_t + \omega_t \partial_5 \ln ub_t + \omega_t$			
			Weighted				Weighted				Weighted				Weighted	
	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.
Panel v-statistic	0.685	0.247	−1.570	0.942	−0.367	0.643	−0.532	0.703	−1.024	0.847	−0.629	0.735	−0.653	0.743	−0.338	0.632
Panel rho-statistic	−0.525	0.300	0.483	0.686	1.600	0.945	0.909	0.818	0.355	0.639	0.247	0.598	0.410	0.659	0.488	0.687
Panel PP-statistic	−.459***	0.000	−1.889**	0.030	0.996	0.840	−0.567	0.285	−2.674***	0.004	−2.706***	0.003	−2.090***	0.018	−1.369*	0.086
Panel ADF-statistic	−5.037***	0.000	−2.775***	0.003	1.032	0.849	−0.679	0.249	−2.796***	0.003	−3.595***	0.000	−2.357***	0.009	−1.860**	0.032
Between-dimension																
	Statistic	Prob.			Statistic	Prob.			Statistic	Prob.			Statistic	Prob.		
Group rho-statistic	1.802	0.964			1.704	0.956			1.546	0.939			1.564	0.941		
Group PP-statistic	−1.910**	0.028			−0.164	0.435			−1.503*	0.066			−0.643	0.260		
Group ADF-statistic	−4.791***	0.000			−1.068	0.143			−2.978***	0.001			−1.356*	0.088		

*, **, and *** represent the 10%, 5% and 1% significance, respectively

*, **, and *** represent the 10%, 5% and 1% significance, respectively

Table 6 Results of Kao panel cointegration for environmental degradation measures

	$\ln builtupf_t = \delta_0 + \delta_2 \ln y_t + \delta_3 \ln(y^2)_t + \delta_4 \ln bio_t + \delta_5 \ln ub_t + \varepsilon_t$		$\ln cf_t = \delta_0 + \delta_2 \ln y_t + \delta_3 \ln(y^2)_t + \delta_4 \ln bio_t + \delta_5 \ln ub_t + \varepsilon_t$		$\ln cropf_t = \delta_0 + \delta_2 \ln y_t + \delta_3 \ln(y^2)_t + \delta_4 \ln bio_t + \delta_5 \ln ub_t + \varepsilon_t$		$\ln fishingf_t = \delta_0 + \delta_2 \ln y_t + \delta_3 \ln(y^2)_t + \delta_4 \ln bio_t + \delta_5 \ln ub_t + \varepsilon_t$	
	t statistic	*p* value	T statistic	*p* value	T statistic	*p* value	T statistic	*p* value
ADF	−6.044***	0.000	−5.924***	0.000	−7.772***	0.000	−1.896**	0.029
Residual variance	0.000		0.002		0.001		0.000	
HAC variance	0.000		0.002		0.000		0.000	
	$\ln forestf_t = \delta_0 + \delta_2 \ln y_t + \delta_3 \ln(y^2)_t + \delta_4 \ln bio_t + \delta_5 \ln ub_t + \varepsilon_t$		$\ln grazingf_t = \delta_0 + \delta_2 \ln y_t + \delta_3 ln(y^2)_t + \delta_4 \ln bio_t + \delta_5 \ln ub_t + \varepsilon_t$		$\ln ef_t = \alpha_0 + \alpha_2 \ln y_t + \alpha_3 \ln (y^2)_t + \alpha_4 \ln bio_t + \alpha_5 \ln ub_t + \mu_t$		$\ln CO_{2t} = \partial_0 + \partial_2 \ln y_t + \partial_3 ln(y^2)_t + \partial_4 \ln bio_t + \partial_5 \ln ub_t + \omega_t$	
	t statistic	*p* value	t statistic	*p* value	t statistic	*p* value	t statistic	*p* value
ADF	−2.302**	0.011	−2.115**	0.017	−8.204***	0.0000	−4.888***	0.000
Residual variance	0.000		0.000		0.004		0.078	
HAC variance	0.000		0.000		0.005		0.080	

*, **, and *** represent the 10%, 5% and 1% significance, respectively

According to FMOLS results in Table 7, the coefficient estimated for biomass energy consumption is negative and statistically significant for ecological footprint. Accordingly, biomass energy consumption contributes to the decrease in ecological footprint and decreases environmental degradation. However, the relevant coefficient is positive and statistically significant for CO_2 emission. This supports that biomass energy consumption is a factor that increases environmental degradation for CO_2 emission. While biomass energy consumption is positive and statistically significant for built-up land, cropland, fishing ground footprint, the sub-component of ecological footprint, it is negative and statistically significant for grazing land, forest pro and carbon footprint (except for forest pro footprint). According to DOLS results, biomass energy consumption is positive only for built-up, CO_2 emission and cropland footprint, but not statistically significant only for CO_2 emission. It is negative and not statistically significant for all environmental degradation criteria (except for forest pro footprint). This result supports that biomass energy consumption decreasing the total ecological footprint increases built-up land, cropland, fishing ground footprint values.

According to FMOLS results in Table 7, urbanization is positive and statistically significant for ecological, built-up and carbon footprint environmental degradation criteria. However, CO_2 emission is negative and statistically significant for cropland, fishing grounds, forest pro and grazing land footprints. According to DOLS results, urbanization is negative and not statistically significant (except for CO_2 emission, cropland and ecological footprint) for all environmental degradation criteria except for built-up footprint.

Considering all the analyses carried out, the results indicating how GDP, GDP^2, biomass energy consumption and urbanization values affect (positively or negatively) the environmental degradation criteria are as in Table 8.

According to Table 8, GDP increases ecological footprint and CO_2 emission for all sub-components except for forest pro footprint. This result supports that economic growth accelerates environmental degradation. This obtained result is similar to the studies of Rahman (2020), Ahmed et al. (2020a), Nathaniel et al. (2021a), Muhammad et al. (2021). GDP^2 is positive for all environmental degradation criteria. Therefore, the EKC hypothesis is not valid for BRICS countries. This result is similar to the findings of the study by Rahman et al. (2021). While urbanization increases built-up and carbon footprints, it decreases all other ecological footprint components. It also decreases both the total ecological footprint and CO_2 emission. While these results are similar to the studies of Mahmood et al. (2020), Ahmed et al. (2020a), Younis et al. (2021), Nathaniel et al. (2021a in that urbanization increases environmental degradation; they are similar to the studies of Ulucak and Khan (2020), Ahmed et al. (2020a, b), in that it decreases environmental degradation. This result contributes to evaluate urbanization as a factor that decreases environmental degradation.

While biomass energy consumption increases built-up, cropland and fishing ground footprints that are the sub-components of ecological footprint, it decreases carbon, forest pro and grazing land footprints. Biomass energy consumption decreases total ecological footprint (increases CO_2 emission); therefore, it causes environmental degradation to decrease (increase). This result is similar to the study of Bilgili et al. (2016), Shahbaz et al. (2017), Dogan and Inglesi-Lotz (2017) in terms of decreasing environmental degradation, and similar to the studies of Solarin et al. (2018) and

Table 7 Long-term estimations for environmental degradation measures

		FMOLS				DOLS			
		GDP	GDP^2	Biomass	Urbanization	GDP	GDP^2	Biomass	Urbanization
Built-up	Coefficient	0.001	0.001	0.003	0.004	0.001	0.001	0.003	0.003
	Std. error	0.001	0.001	0.003	0.001	0.001	0.001	0.007	0.002
	t statistic	2.228	−2.079	9.426	3.442	2.664	−2.664	4.081	1.337
	Prob	0.028**	0.040**	0.000***	0.008***	0.012**	0.012**	0.003***	0.191
Carbon	Coefficient	0.006	0.001	−0.055	0.033	0.002	0.001	−0.014	−0.009
	Std. error	0.005	0.001	0.019	0.006	0.007	0.001	0.019	0.006
	t statistic	1.095	−0.006	−2.956	5.154	3.647	−2.393	−0.754	−0.175
	Prob	0.276	0.999	0.003***	0.000***	0.001***	0.023**	0.457	0.863
Cropland	Coefficient	0.007	0.001	0.028	−0.005	0.001	0.001	0.041	−0.008
	Std. error	0.001	0.001	0.005	0.002	0.001	0.001	0.010	0.003
	t statistic	4.459	−4.410	5.266	−2.930	4.664	−4.937	3.974	−2.719
	Prob	0.000***	0.000***	0.000***	0.004***	0.000***	0.000***	0.000***	0.011**
Fishing-ground	Coefficient	0.002	0.001	0.005	−0.002	−0.001	0.001	−0.009	-0.003
	Std. error	0.001	0.001	0.003	0.001	0.001	0.001	0.006	0.002
	t statistic	2.488	−2.127	1.988	−2.691	−1.651	1.896	−1.408	−0.248
	Prob	0.015**	0.036**	0.049**	0.008***	0.109	0.067*	0.169	0.806
Forestpro	Coefficient	−0.006	0.001	−0.008	−0.008	−0.001	0.001	−0.047	−0.001
	Std. error	0.001	0.001	0.005	0.002	0.001	0.001	0.011	0.003
	t statistic	4.182	−2.518	−1.446	−4.478	−2.339	3.248	−4.165	−0.424
	Prob	0.001***	0.013**	0.151	0.000***	0.026**	0.003***	0.000***	0.674
Grazing land	Coefficient	0.006	0.001	−0.017	−0.007	0.001	0.001	−0.018	−0.006
	Std. error	0.001	0.001	0.004	0.002	0.001	0.001	0.013	0.004
	t statistic	5.076	−4.456	−4.373	−4.912	0.596	−0.556	−1.451	−1.531
	Prob	0.000***	0.000***	0.000***	0.000***	0.556	0.583	0.157	0.136
Ecologic footprint	Coefficient	0.003	0.001	−0.044	0.011	0.001	0.001	−0.045	−0.016
	Std. error	0.007	0.001	0.023	0.008	0.001	0.001	0.033	0.009
	t statistic	4.212	−2.713	−2.025	1.501	2.789	−1.759	−1.381	−1.728
	Prob	0.001***	0.008***	0.046**	0.137	0.009***	0.088*	0.177	0.094*
CO_2	Coefficient	0.002	0.001	0.253	−0.039	0.001	0.001	0.302	−0.196
	Std. error	0.003	0.001	0,099	0.035	0.001	0.001	0.183	0.053
	t statistic	7.229	−6.228	2.533	−1.118	2.365	−2.025	1.649	−3.691
	Prob	0.000***	0.000***	0.012**	0.266	0.025**	0.052*	0.109	0.001***

*, **, and *** represent the 10%, 5% and 1% significance, respectively

Shahbaz et al. (2018) in terms of increasing CO_2 emission and accelerating environmental degradation.

At the same time, this result is also similar to the studies of Liu et al. (2017b) and Pata (2021) (Liu et al. 2017b, 2020; Bhat 2018; Baloch et al. 2019; Wang 2019; Nathaniel et al. 2021b; Khattak et al. 2020; Ulucak and Khan 2020; Akram et al. 2020; Wolde-Rufael and Weldemeskel 2020; Muhammad et al. 2021; Nawaz et al. 2021; Younis et al. 2021; Pata 2021) who resulted that renewable energy consumption in BRICS countries decreased the environmental degradation.

Conclusion and Policy Implications

The effect of biomass energy consumption in BRICS countries on environmental degradation criteria has been examined in this study. For that purpose, CO_2 emission values, ecological footprint and its components "cropland, grazing land cropland, grazing land, forest land, fishing ground, built-up land, and carbon footprint" and GDP, GDP^2, biomass energy consumption and urbanization values belonging to the period of 1992–2018 have been used. Pedroni and Kao Co-integration tests and FMOLS and DOLS analyses have been used in the study. According to the study results, while GDP causes the values of all environmental degradation criteria to increase, it causes only

Table 8 Direction of ınteraction of environmental measures for variables

	Varıables			
	GDP	GDP^2	Bıomass energy consumptıon	Urbanızatıon
Built-up land footprint	+	+	+	+
Carbon footprint	+	+	−	+
Cropland footprint	+	+	+	−
Fishing ground footprint	+	+	+	−
Forest pro footprint	−	+	−	−
Grazing land footprint	+	+	−	−
Total ecologic footprint	+	+	−	−
CO_2 emission	+	+	+	−

+ Statistically significant relationship in the positive direction

− Statistically significant relationship in the negative direction

Only statistically significant results are included

forest, the value of land footprint, to decrease. Accordingly, economic growth becomes a factor that accelerates environmental degradation. According to the result of this study on BRICS countries, GDP is positive for all environmental degradation criteria. This supports the result that the EKC hypothesis is not valid for BRICS countries. Biomass energy consumption values cause built-up land, cropland, fishing ground land footprint values to increase, carbon, forest land, grazing land and ecological footprints to decrease and CO_2 emission to increase. Urbanization causes built-up land and carbon footprint values to increase; however, it causes other environmental degradation criteria values, including CO_2 emission, to decrease. In BRICS countries, according to the results of this study,

- Environmental degradation also increases in BRICS countries depending on the increase in economic growth. For that reason, government and other policy enforcers should develop and implement new strategies, along with policies that protect the environment and reduce environmental pollution, while making decisions to accelerate economic growth.
- Although biomass energy consumption is generally considered an environmental energy resource, it is a resource that increases CO_2 emission. Thus, biomass energy resources should be used carefully also in BRICS countries.
- Urbanization generally decreases both ecological footprint and CO_2 emission. Therefore, urbanization is an essential factor to increase environmental quality. Considering this fact, environment-friendly policies supporting urbanization should be developed.

In future studies on BRICS countries, the effect of consumption of different energy sources on environmental degradation can be examined. In addition, these examinations for BRICS countries can be made one by one and comparisons can be included.

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Availability of data and materials Data are available from the author(s) on reasonable request.

Declarations

Conflict of interest The authors declare no competing interests.

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