Research Paper

Assessing the Environmental Sustainability Corridor for BRICS Nations by Integrating Three SDGs, 'Biocapacity' and 'Ecological Footprint'

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Abstract

The present study makes an attempt to analyse the co-integrating relation between 'ecological footprint' on one hand and GDP, trade openness, forest area and biocapacity on the other for the period 1992–2015 for five BRICS economies with the objective of ascertaining whether the rapid growth achieved by the BRICS is along a 'sustainable' path. Further, the study also tries to lookout for signs of 'convergence' of 'ecological footprint' amongst all BRICS economies. The methodology employed includes ARDL Co-integration Model, TY Causality and Beta Convergence Models. The results showed existence of long run co-integration amongst four BRICS nations (except for India where no co-integration was proved) with fast speed of adjustment towards long run equilibrium. Further, short-run causality was seen moving from 'GDP' and 'forest area' towards 'ecological footprint' in three of the five BRICS nations, while variable 'trade' was not seen causing 'ecological footprint'. 'Beta convergence' was also proved for 'ecological footprint' amongst all BRICS nations. These results thus provide a clear indication as to which variables need to be targeted to achieve a 'sustainable' growth. The results also reveal the pace of long-term adjustment as shown by ECM(−1) term, which would enable policymakers to plan their action for fulfilment of the objective of tackling 'environmental degradation' in BRICS economies. Also, convergence of 'ecological footprint' across BRICS indicates that similar policies to tackle environmental degradation could be framed for BRICS at their group meetings.

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Introduction

The controversy regarding who was more responsible for the current state of environmental degradation and who should bear the costs for the same has been for a long and the topic has been discussed in many global summit meetings of the country heads. Meanwhile, realising that ending poverty, health, education and other deprivations are closely linked to environmental degradation, the United Nations in 2015 adopted 17 Sustainable Development Goals (SDGs) to be achieved by member nations by 2030.[1] The main motive behind these SDGs is to make a country's growth and development sustainable.

Taking a clue from above, our study has been designed to examine whether the growth achieved by some of the fast-developing economies follows a sustainable pattern, and to this end, we have included BRICS nations—Brazil, Russia, India, China and South Africa—in our sample. The choice of BRICS is strongly influenced by the separate growth stories of each of the BRICS's economies. BRICS bloc has become one of the most growth-oriented blocks and shares a lot of common features like abundant natural resources, fast-evolving services sector and a strong agrarian base, amongst others (Sharma & Shahani, 2018). The importance of the BRICS bloc lies in its contribution to world GDP and the world's share of trade. BRICS contribution to world GDP has risen from 11.9% in 2000 to 25.6% in 2021, while share in world exports stands at 10%. Perhaps the biggest achievement of the BRICS bloc is in terms of reduction of poverty rates, and all the countries belonging to the BRICS group managed to surpass the targets set for them in Millenium Development Goals (MDGs) adopted at the 2000 UN Summit (Agarwal & Kumar, 2023).

Moving to our study objective, which ascertains whether or not the rapid growth achieved by the BRICS is along a 'sustainable' path, we have developed a co-integrating relationship for which we have selected five variables; three of the five variables, namely trade openness, GDP and forest area have been taken from SDGs of the United Nations, while the remaining two are complex variables—'ecological footprint' and 'biocapacity'—both sourced from the Global Footprints Network.[2]

The inclusion of two complex variables was necessitated as most traditional proxies for environmental degradation had failed to provide a comprehensive picture of its degradation. The first complex variable, 'ecological footprint', represents a combined environmental impact of all human activities. It measures the impact of all goods and services produced and all waste generated (Network, 2014; Rashid et al., 2018). 'Ecological Footprint' covers six categories of land types: forest land, grazing land, cropland, built-up land, ocean and carbon footprint. It covers resources demanded by individuals, businesses and governments and makes a comparison with what resources the 'Earth' can renew in a sustained manner (Nathaniel & Khan, 2020). The variable is measured in global hectares and takes the shape of a dependent variable in our study.

The second complex variable included is 'biocapacity', which represents the country's bioproduction area and includes the sum total of land, wasteland and sea to produce goods and services. This too is expressed in global hectares and makes a strong case against 'ecological footprint'. A country may have 'biocapacity' higher or lower than 'ecological footprint'. Biocapacity hurts 'ecological footprint' and is ideally expected to be negatively related to our dependent variable 'ecological footprint'.

Furthermore, amongst these three SDGs, included in our study, two are linked to the growth of an economy, namely GDP and trade openness, and both can have either a positive or negative relation with 'ecological footprint'. This relation, however, also depends upon the country's approach towards growth and development, and as stated above, is one of the thrust areas of the current study, that is, to analyse the growth of each of the BRICS nations from the angle of 'sustainability'.

The third SDG variable is 'forest area' and the reason for its inclusion is a massive decrease in 'forest area' in some of the BRICS nations on account of the acquisition of land to support growth and development projects. Hence, it would be interesting to explore the quantum of relation this variable has with 'ecological footprint'. For all three SDGs, we obtain data from World Development Indicators with the period of data being 1992–2015.[3] The choice of the study period is strongly influenced by coming into existence of the 'BRICS' acronym in 2001 (O'neill, 2001), and the study considers data 10 years before this date till the year for which last information was available on all the variables from the World Bank website. Thus, by exploring the relation of the variables included in our study with 'ecological footprint', the study aims to understand whether the growth achieved by these fast-developing economies follows a sustainable pattern or not. Table 1 provides a summary of the variables included in our study along with their unit of measurement.

Another objective of the study is to look at the aspect of 'convergence' of all BRICS economies in the long run with respect to the variable 'ecological footprint', and to achieve this novel concept, we would be developing a model for 'beta convergence' for our dependent variable 'ecological footprint', which considers the pooled annualised average growth rate of all BRICS nations to be regressed against initial emissions.

Table 1. Summary Information of the Variables Included and their Sources of Data

Sr No.	Name of the Indicator	Unit of Measurement	Source of Data
1	Ecological footprint	Global hectares per capita	Global Footprints Network (GFN) (2023)
2.	Biocapacity	Global hectares per capita	Global Footprints Network (GFN) (2023)
3.	Economic growth	GDP per capita constant 2015 prices	World Development Indicators
4.	Trade openness	Merchandise {Sum of exports and imports (% of GDP)},	World Development Indicators
5.	Forest Area	Forest area as a % of total land area	World Development Indicators

Review of Literature

Under the literature review we have included studies that have tried to link 'ecological footprint', the dependent environment proxy variable in our study with a host of other variables, including traditional and popular variables, such as energy consumption, renewable energy trade, GDP, etc. and some of the newly introduced variables like democracy, environmental regulations and also complex variables like biocapacity.

Our review begins with three studies—Danish et al. (2020), Ahmed et al. (2022) and Fotis and Polemis (2018)—where they considered 'environmental regulations' (*environmental patents as its proxy*) against 'ecological footprint'. The results from all three studies revealed that 'environmental regulation' decreased 'ecological footprint'. In another study, Sarkodie and Adams (2018) working in a related area of 'environmental regulations' showed how quality of governance plays an important role in the implementation of 'environmental regulations'. On the other hand, researchers have also shown that the variable 'environmental regulations' also entails a lot of indirect benefits for the betterment of the environment like stimulating renewables and discouraging non-renewables. Furthermore, while working on variable 'environmental regulations' researchers have also noticed that this variable being a state-managed affair, with its implementation too being state responsibility, the standards followed across nations differ vastly, which has also impacted findings of researchers working on his variable.

Yet another newly introduced variable explored by the researchers in their studies against 'ecological footprint' is 'democracy'. This variable is often linked to freedom of speech and freedom of the press (media). It also includes the accessibility of the public to vital information. As far as the relation of this variable with 'ecological footprint' goes, the results in many studies have shown a negative relation (e.g., see Payne, 1995). Furthermore, researchers have also linked this variable 'democracy' to another variable 'environmental regulations', and the logic provided was that the general public can force the government to enact stringent 'environmental regulations' leading to improvements in 'ecological footprint'. Then, the 'Democratic Accountability Index', a variant of this index, was used in a study by Ahmed et al. (2022), and they too tried to link the variable to 'ecological footprint'; however, the relation was found to be negative.

Speaking of the complex variable included in the study, a variable that has caught the attention of the researchers is 'biocapacity'. A research article by Hassan et al. (2019) showed that biocapacity as a variable too was negatively related to 'ecological footprint' and many researchers have also found this to be true.

Coming to the traditional and popular variables and their relation with 'ecological footprint', the first variable under consideration is 'growth' which is proxied by variables, such as 'GDP', 'income', 'per capita' and so on. Then, by virtue of its close linkages with mass consumption of resources, the relation between 'growth' and 'ecological footprint' has been found to be positive in the majority of the studies. Another traditional macro-economic indicator that has been studied in most studies against 'ecological footprint' is 'trade'. This indicator is known to work in both directions with respect to 'ecological footprint'; the variable has a positive relation with 'ecological footprint' in case of a high flow of energy-intensive technology into the country; however, the same variable was seen decreasing 'ecological footprint' where the imports were mainly in green technology, thereby making way for technology substitution (Ahmed et al., 2022; Murshed et al., 2021).

One variable that has been extensively studied against 'ecological footprint' is 'renewables energy' (Nathaniel et al., 2020a, 2020b; Radmehr et al., 2022). Radmehr et al. (2022) in their comprehensive study on G7 nations concluded that even in high-income countries, 'renewable energy' was not effectively utilised and the rapid economic development of these nations was mainly by using fossil fuels, which had actually resulted in the depletion of natural resources and hence contributed to environmental destruction. The primary reason for all countries (developed or developing) resorting to fossil fuels for development was the high substitution costs, which were preventing countries switching from non-renewables to renewables, even though the variable was making a positive impact and resulting in a fall in 'ecological footprint' as seen in the majority of research studies. Whereas Nathaniel and Khan (2020) proved the same for six ASEAN economies, Danish and Khan (2019) found the same to be true for BRICS economies. On the other hand, Hastik et al. (2016) showed that renewable energy alone was not capable of addressing a country's environmental problems in the long run and must be accompanied by other steps, such as developing its own energy-saving production processes. Then, a lot of researchers have clubbed 'renewable energy' with other variables; for example, Danish and Khan (2019) clubbed the same with another variable 'urbanisation' while Murshed et al. (2021) clubbed it with 'environmental regulations'. The results from both studies showed that jointly, after clubbing, there was an enhanced reduction in 'ecological footprint'.

Next, we discuss the two popular and related variables, 'age' and 'life expectancy', and their impact on 'ecological footprint' and the environment in general. With respect to variable 'age', a general viewpoint is that as people grow older, their attachment towards the environment rises; however, empirical evidence for the same points otherwise. This was seen in a study by Zagheni (2011) where 'age' was found to be positively related to 'ecological footprint'. Then 'life expectancy' a close associate of 'age' was also found to be positively related to 'ecological footprint'. However, urban 'life expectancy', a subset of 'life expectancy', was found to be enjoying a more positive and stronger relation with the 'ecological footprint' than other subsets, rural 'life expectancy'.

Another variable that has been studied frequently by the researchers against 'ecological footprint' is 'urbanisation'. Although the variable 'urbanisation' was found to be positively related to 'ecological footprint' in a number of studies (Ahmed, 2020; Ansari, 2020; Nathaniel et al., 2020b), there are some studies like Danish and Khan (2019) that gave a contradictory viewpoint and showed that 'urbanisation' improved environment quality.

Thus, the review of the literature given above does give some idea about how different macro variables, which have been conveniently classified as traditional, non-traditional and complex variables, are related to the variable 'ecological footprint'. Thus, there are three important takeaways from the above review; first, barring one or two variables, most traditional variables do promote environmental degradation and hence are positively related to 'ecological footprint', while the same is not true for most non-traditional variables; second, the relation between non-traditional variables and 'ecological footprint' apart from being negative appears to be much stronger as compared to traditional variables; and third, very few studies have tried to explore the relation of 'ecological footprint' by including its counterpart 'biocapacity'. Since both the variables 'ecological footprint' and 'biocapacity' are complex in nature and sourced from a common source, 'Global Footprints Network', the nature of their formulation is such that they enjoy a negative relation. Thus, it is important for inclusion of both of these complex variables to get meaningful results from the study; otherwise, there is a very strong chance of omission and model misspecification.

In light of the above discussion, we develop our study with the objective of establishing a co-integrating relationship for BRICS nations with variable 'ecological footprint' on one hand and three SDG goals, namely trade openness, GDP and forest area as variables on the other. We also include 'biocapacity' as a main control variable representing the country's bioproduction area. Further in the study, we shall also make an attempt to develop a β-convergence model for 'ecological footprint' for BRICS nations, which would determine whether or not the countries of the BRICS group have a long-run convergence. These objectives are achieved by establishing three models: an ARDL co-integration model, a causality model and a β-convergence model. So that the models are robust, we carry out all the diagnostics (serial correlation and heteroscedasticity) and, more importantly, consideration that none of the variables included are integrated at levels I(2) or higher.

Methodology

Under this section, we would be developing three models: co-integration, causality and convergence models. Our first model establishes a cointegrating relationship using ARDL methodology (Pesaran & Shin, 2001; Pesaran et al., 1999) for BRICS nations between 'ecological footprint' and four other variables. Amongst various co-integration models, the selection was made for the ARDL model after considering two important aspects; first was to obtain efficient results even for a small-sized sample, and second, to select a model that gives robust results when the stationarity levels of variables include a mix of I(0) and I(1) (see Shahani & Aayushi, 2019).

Further, we have developed two equations under the ARDL framework, first being the ARDL representative equation (Equation (1)), a single representative equation, which provides information about both short- and long-run variables, and second, the ECM equation (Equation 2), which shows the adjustment from disequilibrium in the short run to equilibrium in the long run. However, the results obtained from Equation (2) need to be interpreted only after co-integration is confirmed under the study for which we have applied the 'F' bounds test with critical values of the same being provided by Pesaran et al. (1999).

ARDL Representative Model

$$
\text{''}\,\mathrm{EFP}_t = \delta_1 + \delta_2 \mathrm{EFP}_{t-1} + \delta_3 \mathrm{GDP}_{t-1} + \delta_4 \mathrm{TO}_{t-1} + \delta_5 \mathrm{BC}_{t-1} + \delta_6 FA_{t-1} + \sum\nolimits_{i=1}^{n}\left(\delta_{7,i}\,\text{''}\,\mathrm{EFP}_{t-i}\right) + \sum\nolimits_{i=0}^{n}\left(\delta_{8,i}\,\text{''}\,\mathrm{GDP}_{t-\mathrm{i}}\right) + \sum\nolimits_{i=0}^{n}\left(\delta_{9,i}\,\text{''}\,\mathrm{TO}_{t-i}\right) + \sum\nolimits_{i=0}^{n}\left(\delta_{10,i}\,\text{''}\,\mathrm{BC}_{t-i}\right) + \sum\nolimits_{i=0}^{n}\left(\delta_{11,i}\,\text{''}\,FA_{t-\mathrm{i}}\right) + u_{1,t} \quad (1)
$$

For Equation (1), EFP is the ecological footprint, GDP is gross domestic product, TO denotes trade openness, BC represents biocapacity and FA is the forest Area. $u_{1,t}$ is the residual error term for Equation (1). Model (1) regresses change in ERP against the first lag of all the variables, including dependent variable EFP, thereby creating a long-run relation between 'ecological footprint' and other variables. The model also includes short-run variables shown as the change in lag of each variable, summed up to 'n', with 'n' being optimal lag length provided by AIC lag criteria.

ARDL ECM Equation

$$
\Delta \mathrm{EFP}_t = \theta_1 + \theta_2 ECM_{t-1} + \sum\nolimits_{i=1}^{n}\left(\theta_{3,i}\Delta \mathrm{EFP}_{t-i}\right) + \sum\nolimits_{i=0}^{n}\left(\theta_{4,i}\Delta \mathrm{GDP}_{t-i}\right) + \sum\nolimits_{i=0}^{n}\left(\theta_{5,i}\Delta \mathrm{TO}_{t-i}\right) + \sum\nolimits_{i=0}^{n}\left(\theta_{6,i}\Delta \mathrm{BC}_{t-i}\right) + \sum\nolimits_{i=0}^{n}\left(\delta_{7,i}\Delta \mathrm{FA}_{t-i}\right) + u_{2,t} \quad (2)
$$

Equation (2) is the equation for Error Correction Mechanism (ECM) and has change in EFP as a dependent variable. The term, ECM_{t-1} is the first lag coefficient of residuals obtained by running the equation of long-run variables, while the rest of the variables are short-run variables, which were also included in Equation (1). The term ECM_{t-1} assumes importance as it reflects the speed at which short-run disequilibrium gets corrected in the long run, and to be meaningful, this coefficient must be negative and statistically significant.

The Causality Model

For testing causality, we apply Toda and Yamamoto (1995) modified 'F' model. The choice of this model (TY) is again based upon the level of integration of included variables. Under TY causality, for say two variables X_1 and X_2, we develop two models (3) and (4), the first being a restricted model and the second one as unrestricted. Under TY methodology, both models, model (3) and (4), are lag augmented by taking the higher level of integration ((I)high) of the causal variables, which gets added to the optimal number of lags obtained by using AIC criteria. Upon running the two regressions, we obtain the sum of the squared residuals (SSR_R and SSR_{UR}), which we use to obtain modified 'F' to test for the existence of causality amongst the two variables.

$$
\text{Mod } \mathrm{F}_{\mathrm{Wald'}} = \frac{(\mathrm{SSR_R} - \mathrm{SSR}_{UR})/\mathrm{k}}{\mathrm{SSR_{UR}}/\left(\mathrm{n}-\mathrm{k}\right)}
$$

Restricted Model (R)

$$X_{1t(R)} = \tau_{0(R)} + \sum_{j=1}^{(I)high} \alpha_{j,(R)} X_{2,(t-j)} + \sum_{i=1}^{h+(I)high} \beta_{i,(R)} X_{1,(t-i)} + e_{1t} \quad (3)$$

Un-Restricted Model (UR)

$$X_{1t(UR)} = \tau_{0(UR)} + \sum_{j=1}^{k+(I)high} \alpha_{j,(UR)} X_{2,(t-j)} + \sum_{i=1}^{k+(I)high} \beta_{t,(UR)} X_{1,(t-i)} + e_{2t} \quad (4)$$

Model for Beta Convergence

The concept of 'convergence' which was originally used to study reduction of income inequalities amongst nations has now been extended to other variables including environmental indicators (Omojolaibi et al., 2020). Under the study, we develop a model for 'beta convergence' for our dependent variable 'ecological footprint'. 'β-convergence' model assumes linear relation amongst variables and the model is given as Equation (5):

$$\beta - \text{convergence} = \ln\left|\frac{\text{EFP}_{i,t+k}}{\text{EFP}_{i,t}}\right| = \beta_1 + \beta_2 \ \ln.\ \text{EFP}_{i,t} + u_{i,t} \quad (5)$$

For Equation (5), $\text{EFP}_{i,t}$ is the emission in initial time say 't', while $\text{EFP}_{i,t+k}$ are the emissions in time '$t+k$'. Under the model, we take $k = 10$ years. Equation (5) thus considers annualised average growth rate of the i^{th} BRICS nation for the 10-year period as a dependent variable, which is regressed against initial emissions for the same BRICS nations and the entire process is carried out at a pooled level. The 'convergence' occurs if the two coefficients, as given in Equation (5), β_1 and β_2 are statistically significant but with dissimilar signs (i.e., if one is positive then other must be negative and statistically significant). Another condition to be satisfied is that the slope coefficient $\beta_2 < 0$ (Tiwari & Mishra, 2017).

ARDL Model Pre-requisites and Diagnostics

After building three models, we next state the methodology adopted for model pre-requisites and diagnostics. Under this section, we will be discussing the methodology for model pre-requisite, namely variable stationarity and two diagnostics: serial correlation and heteroscedasticity.

For the stationarity pre-requisite, we would be applying the popular ADF unit root test; the equation for the same is given as Equation (6). Next for residual-based diagnostics, namely serial correlation and heteroscedasticity, we would be applying 'Q' statistics (Equation (7)) and the White (1980) heteroscedasticity test (Equation 8).

$$\Delta X_t = \beta_1 + (\beta_2 - 1) X_{t-1} + \sum_{i=1}^{m} \beta_{3,i} \Delta X_{t-i} + e_t \quad (6)$$

Equation (6) is the ADF stationarity equation, where $\beta_2 - 1$ is the coefficient for X_{t-1} whose computed '*t*' is compared with table 'tau *t* values' to determine the level of stationarity. Further, the equation also includes a coefficient $\beta_{3,i}$ which takes care of serial correlation, while β_1 is the constant.

Next, for two residual-based diagnostics, namely serial correlation and heteroscedasticity, we first run the regression and obtain the residuals. For serial correlation, we apply the formula

$$Qm = n\sum_{i=1}^{m} \rho_{u_{i,t}}^2 \tag{7}$$

where 'Q_m' ~ χ^2 distribution with '*m*' being df or simply the number of lags. Null (H_o) for the same being $\rho_{u_{1t}} = \rho_{u_{2t}} = \ldots = \rho_{u_{mt}} = 0$, while alternative being some of the $\rho_{u_{it}}$ are not equal to 0.

We further define $\rho_{u_{1t}} = \dfrac{\text{cov}\left(u_{t,}u_{t-1}\right)}{\sqrt{\text{Var}_{(u_t-1)}\text{Var}_{(u_t)}}}$ and the study computes serial correlation at lags 1, 5 and 8. For the heteroscedasticity test, we use the test developed by White (1980). The test requires an auxiliary equation with the square of residuals as the dependent variable, that is, Equation (8):

$$u^2{}_t = \varphi_1 + \varphi_2 X_{1t} + \varphi_3 X_{2t} + \varphi_4 X^2{}_{1t} + + \varphi_6 X_{1t} X_{2t} + e_t \tag{8}$$

Null Hypothesis heteroscedasticity test: H_o: $\varphi_2 = \varphi_3 = \varphi_4 = \varphi_5 = \varphi_6$ (i.e., residuals are homoscedastic).

Results and Discussion

This section gives the results of the study duly supported by Tables 2–6. Table 2 gives the results of our long-run co-integration, for which we had established an ARDL co-integrating model for each of the BRICS nations. The results revealed that in four of the five BRICS nations, namely Brazil, Russia, China and South Africa co-integration was proved, while only for India this was not seen under the study results. The computed 'F' statistics under bounds test for all the countries (except India) were higher than the upper bound critical, while this was lower than the lower bound for India (Table 2).

Thus, having proved for co-integration in four out of five countries, the next logical step was to establish the speed of adjustment from short-run disequilibrium to long-run equilibrium. The results of the same are shown in Table 3, with the speed of adjustment towards equilibrium given under column 2 of the table. The movement appears to be quite fast, with the long-run adjustment process getting completed in 1–3 years for all four countries except India. For India, co-integration was not established under the study.

The next set of results pertains to causality (Table 4) and we have tested for uni-directional causality from all four variables towards 'ecological footprint' for all five BRICS nations. The results revealed that two variables, namely 'GDP' and 'forest area' were causing an 'ecological footprint' in three of the five BRICS

Table 2. Co-integration Results for BRICS Using 'F' Bounds Test Under ARDL.

Country	'F' Statistics	Critical 'F'(Lower Bound) 5% Level	Critical 'F'(Upper Bound) 5% Level	Results
Brazil	7.7	3.12	4.25	Co-integration
Russia	23.9			Co-integration
India	3.05			Co-integration not proved
China	15.7			Co-integration
S. Africa	9.3			Co-integration

Result: *Co-integration was proved for all BRICS except for India.*

Table 3. ECM Results for BRICS and Adjustment Speed to Long-run Equilibrium.

Country	Speed of Adjustment to Long-Run Equilibrium (years)	Computed ECM Value	'*p*' Statistics
Brazil	3.06	−0.327	.0001
Russia	2.22	−0.45	.0000
India	*Not applicable as long run co-integration not proved*		
China	1.75	−0.57	.0005
S. Africa	1.39	−0.72	.0001

Table 4. Unidirectional Causality Results.

Country	Direction of Relation	Chi Square	'*p*' Value	Null Hypothesis (Accept /Reject)
Brazil	Biocapacity → Ecological footprint	0.0197	.991	Accept, No Causality exists
Brazil	Trade Openness → Ecological footprint	2.2536	.324	Accept, No Causality exists
Brazil	Forest Area → Ecological footprint	0.0851	.9583	Accept, No Causality exists
Brazil	GDP → Ecological footprint	5.2193	.0361	*Reject, Causality exists*
Russia	Biocapacity → Ecological footprint	8.8515	.012	*Reject, Causality exists*
Russia	GDP → Ecological footprint	0.0979	.952	Accept, No Causality exists
Russia	Trade Openness → Ecological footprint	2.7073	.258	Accept, No Causality exists
Russia	Forest Area → Ecological footprint	3.0553	.2170	Accept, No Causality exists
China	Biocapacity → Ecological footprint	1.4352	.487	Accept, No Causality exists
China	GDP → Ecological footprint	7.7787	.025	*Reject, Causality exists*
China	Trade Openness Ecological footprint	3.8499	.146	Accept, No Causality exists

(Table 4 continued)

(Table 4 continued)

Country	Direction of Relation	Chi Square	'p' Value	Null Hypothesis (Accept /Reject)
China	Forest Area → Ecological footprint	5.4491	.035	*Reject, Causality exists*
India	Biocapacity → Ecological footprint	4.4747	.1067	Accept, No Causality exists
India	GDP → Ecological footprint	6.7931	.0335	*Reject, Causality exists*
India	Trade Openness → Ecological footprint	2.3759	.306	Accept, No Causality exists
India	Forest Area → Ecological footprint	6. 9107	.031	*Reject, Causality exists*
South Africa	Biocapacity → Ecological footprint	3.5219	.172	Accept, No Causality exists
South Africa	GDP → Ecological footprint	0.1565	.925	Accept, No Causality exists
South Africa	Trade Open → Ecological footprint	3.1557	.206	Accept, No Causality exists
South Africa	Forest Area → Ecological footprint	8.1624	.0205	*Reject, Causality exists*

Result: *Short-run causality moves from 'GDP' and 'forest area' towards 'ecological footprint' in three BRICS nations and from 'biocapacity' towards 'ecological footprint' in Russia.*

Table 5. Results of Beta Convergence for 'Ecological Footprint'.

	Coefficient	Standard Error	*t* Statistics	'*p*' Value
β_1	1.315127991	0.041979614	31.32778	6.60E–90
β_2	–0.499310074	0.016126118	–30.9628	7.20E–89

Result: *The convergence stands proved as β_1 and β_2 are significant (as given by 'p' values and 't' statistics) but with opposite signs and $\beta_2 < 0$. The test applied was* $ln\left|\frac{EFP_{i,t+k}}{EFP_{i,t}}\right| = \beta_1 + \beta_2 \ln . EFP_{i,t} + u_{i,t}$.

nations. Then, uni-directional causality was also seen moving from biocapacity towards 'ecological footprint' in only one country, that is, Russia. Further, the only variable that was not seen causing an 'ecological footprint' in any of the BRICS was 'trade openness'.

Moving to Table 5 results, which pertain to test results of 'beta convergence' for our variable, 'ecological footprint', and the results show that 'convergence' stands proved for 'ecological footprint' amongst all BRICS nations as revealed by the sign and significance of coefficients β_1 and β_2 from Equation (5), which were found to be significant with opposite signs.

Finally, we have results of Tables 6–7, which pertain to model diagnostics and model pre-requisites. Table 6, which gives the results of stationarity tests using ADF unit root methodology, clearly reveals the mixed nature of our variables, some as I(0) while the rest as I(1) integrated. Whereas GDP was stationary at level for Brazil, this was at first difference for the rest of the BRICS, as shown by the

Table 6. Results of Test for Variables Stationarity for BRICS (Unit-Root ADF).

			Brazil		Russia		India		China		South Africa	
Name of the Variable	Type of Model	Null Hypothesis	Computed ADF '*t*' values at level ('*p*' values in parenthesis)	Computed ADF '*t*' values at I diff ('*p*' values in parenthesis)	Computed ADF '*t*' values at level ('*p*' values in parenthesis)	Computed ADF '*t*' values at I diff ('*p*' values in parenthesis)	Computed ADF '*t*' values at level ('*p*' values in parenthesis)	Computed ADF '*t*' values at I diff ('*p*' values in parenthesis)	Computed ADF '*t*' values at level ('*p*' values in parenthesis)	Computed ADF '*t*' values at I diff ('*p*' values in parenthesis)	Computed ADF '*t*' values at level ('*p*' values in parenthesis)	Computed ADF '*t*' values at I diff ('*p*' values in parenthesis)
Trade openness	Intercept & Trend	Trade openness has a unit root	−1.509274 (0.7964)	−4.328967 (0.0168)	−3.329315 (0.0865)	−4.222015 (0.0203)	−0.496556 (0.9760)	−3.925823 (0.0283)	−3.259886 (0.0991)	−0.561738 (0.038)	−3.323887 (0.0897)	−4.879121 (0.0057)
Biocapacity	Intercept & Trend	Biocapacity has a unit root	−2.567829 (0.2791)	−3.221910 (0.0131)	−3.817118 (0.0341)	−6.316337 (0.0002)	−2.852504 (0.1945)	−6.183105 (0.0003)	−3.338246 (0.0902)	−8.179770 (0.0000)	−4.858513 (0.0039)	−7.401379 (0.0000)
Ecological footprint	Intercept & Trend	Ecological footprint has a unit root	−3.429659 (0.0787)	−3.699652 (0.0440)	−3.092764 (0.1344)	−4.212651 (0.0167)	−1.445899 (0.8186)	−5.410874 (0.0013)	−2.224730 (0.4540)	−1.223367 (0.0400)	−2.005255 (0.5680)	−6.294368 (0.0002)
GDP	Intercept & Trend	GDP has a unit root	−3.757337 (0.0416)	−2.799617 (0.0018)	−3.329315 (0.0865)	−2.942161 (0.044)	0.009679 (0.9937)	−3.175077 (0.049)	−2.642087 (0.2676)	−2.186514 (0.046)	−3.310997 (0.0905)	−3.371761 (0.0424)
Forest area	Intercept & Trend	Forest area has a unit root	−0.438637 (0.9788)	−4.638406 (0.0071)	−2.407955 (0.3657)	−3.586845 (0.0450)	−2.726659 (0.2363)	−1.176305 (0.006)	−1.913514 (0.6136)	−4.304844 (0.0139)	−3.735270 (0.0462)	−3.538768 (0.0671)

Notes: (1) Model included 'trend and intercept', level of significance: 5%.
(2) Critical 't' value at 5% level for ADF (with trend and intercept) at level is −3.622033 and at first difference is −3.632892.

Table 7. Diagnostics: Serial Correlation and Heteroscedasticity for BRICS.

	Brazil	Russia	India	China	South Africa
A Heteroscedasticity Test: White (1980)					
1. Observed R^2	6.920177	7.407842	5.351089	11.66373	6.603983
2. Probability χ^2	0.4372	0.8295	0.8665	0.5554	0.4712
B Serial Correlation: Using '*Q*' Statistics					
Lag 1 Statistics and	0.2249	3.2927	0.0592	4.1960	0.2340
('*p*' values)	(.635)	(.070)	(.808)	(.071)	(.629)
Lag 5 Statistics and	8.0765	9.1299	4.3912	7.0875	2.8489
('*p*' values)	(.152)	(.104)	(.495)	(.214)	(.723)
Lag 8 Statistics and	11.531	13.012	6.1240	8.0504	7.4556
('*p*' values)	(.173)	(.111)	(.633)	(.429)	(.488)

Result**:** *The results clearly reveal that (a) homoscedasticity and (b) no serial correlation for all the five BRICS nations.*

'*p*' values given in parentheses in Table 6. Again, biocapacity was stationary at I(0) for Russia and South Africa and the same was I(1) for the rest of the BRICS nations. Then, moving to our last table, Table 7, which gives the results of serial correlation and heteroscedasticity, and the table clearly shows that both the diagnostics are adequately satisfied for all the BRICS nations under the study.

Conclusion and Implications

To conclude, the study developed a co-integrating relation between 'ecological footprint' on one hand and GDP, trade openness, forest area and biocapacity on the other for the period 1992–2015 for five BRICS economies. The objective of the study was to determine whether or not the rapid growth achieved by BRICS nations was following a 'sustainable' path. Another study objective was to look for signs of 'convergence' of variable 'ecological footprint' for all BRICS economies. To achieve these objectives, the study employed the ARDL co-integration model, TY causality and β-convergence models. In the study results, co-integration was proved for four BRICS nations (except India) with a fast speed of adjustment towards long-run equilibrium for each of the four BRICS; the adjustment process was seen completing in 1–3 years. Then, short-run causality was seen moving from 'GDP' and 'forest area' towards 'ecological footprint' in three of the five BRICS nations, while variable 'trade' was not seen causing 'ecological footprint' in any of the BRICS. Further, there was evidence of 'convergence' for 'ecological footprint' amongst all BRICS nations.

The study results for variable 'ecological footprint' being strongly co-integrated with other four variables in four BRICS are in line with existing studies, including Ahmed et al. (2022), Ansari (2020). These results thus provide a clear direction to the policymakers of BRICS nations, and if we club the results pertaining to co-integration and causality, we get a better idea as to which variables need to be targeted if the goal of sustainable development was to be achieved by each of the BRICS within the time frame set by the United Nations. If we go by the study results, then variables ‘GDP’ and ‘forest area’ are the variables that require the highest attention, while the least attention could be towards ‘trade’; variable was not seen impacting ‘ecological footprint’. The fast pace of movement towards equilibrium as given by the ECM(−1) term gives a lot of encouragement to policymakers as it reveals the pace at which their action would get channelised and transmitted for fulfilment of its objectives. This would also assist the policymakers in developing right-directional policies with precise targets of timely response thereby deciding upon a precise roadmap towards controlling ‘environment degradation’ in each of the BRICS nations. The other useful result obtained under the study was the proving of convergence of ‘ecological footprint’ across BRICS, which provides an indication that similar policies can be framed for all BRICS at their group meetings in order to jointly address and mitigate this global concern.

Finally, before we end, we would like to give some future directions for research in this area, which is fast becoming highly sought-after research in social sciences owing to its global importance. Researchers working in this area could add few more variables against the dependent variable ‘ecological footprint’ that have not been included in the study, for example, population, renewable and non-renewable energy, and a host of non-traditional variables, including environmental regulations and democracy; some of these have been discussed under review of literature. Then, non-linear methodology which is gaining popularity for econometric modelling may also be considered by the researchers. Researchers may also consider a ‘switching regression’ if they are of the opinion that the variable ‘ecological footprint’ has undergone a regime change that needs to be incorporated to make their research more meaningful. This would however require extending the period of study to include a sufficient number of years so that variables undergoing a regime shift are able to display a clear shift from one regime to another. Furthermore, researchers could consider extending the coverage of their samples to include more countries, which could also be pooled together into one to make the work more purposeful.

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Notes

1. https://sdgs.un.org/goals
2. https://www.footprintnetwork.org/
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