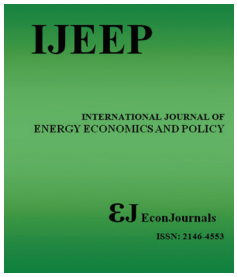

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Does Trade Openness Mitigate Environmental Degradation in BRICS Countries? An Empirical Analysis from PMG-ARDL and Panel DOLS Model Technique

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ABSTRACT

The fundamental feature of the modern world is the preservation of environmental quality, as well as the restoration of renewable resources, the promotion of green and clean energy, and the advancement of sustainable development. The objective of the research is to examine the influence of trade openness on environmental mitigation in a group of BRICS nations from 1990 to 2021. This will be done by taking into account factors such as GDP per capita, financial development, energy consumption, and urbanisation. The PMG-ARDL model methodologies indicate that GDP per capita, trade openness, and urbanisation have a long-term mitigating effect on environmental quality in a panel of BRICS nations. The results suggest that in the near term, GDP per capita, financial development, energy consumption, and urbanisation have adverse effects on environmental mitigation, whereas trade openness does not have a negative impact. Moreover, the panel DOLS analysis reveals that GDP per capita, trade openness, energy consumption, and urbanisation in the BRICS nations have a substantial and negative impact on environmental quality. Nevertheless, the results obtained from the PMG-ARDL estimator and the panel DOLS indicate that there is no detrimental effect of financial development on environmental quality. These empirical results provide useful insights for several stakeholders, such as government authorities, politicians, regulators, practitioners, and researchers.

Keywords: Environmental Degradation; Trade Openness; GDP; Financial Development; BRICS Countries
JEL Classifications: Q5, E310, L11, F6

1. INTRODUCTION

The sustainable development, renewable resources, and green and clean energy have been widely recognised as important areas of concern in recent times across the countries in the world. It has been seen that the present phase of economic growth and development is lacking environmental sustainability. The rising CO_2 emissions globally put a question on our phase of growth and development agenda how long the environmental quality be sustained? China which emerged as one of the largest drivers of international trade has now become one of the largest sources of CO_2 emissions. Yang, 2017 and Ahmad et al. (2015), in their study, observed that energy resources, CO_2 emissions, nitrous oxide, methane, use of fossil fuels, smoke expulsion by the factories and the use of wood as a source of energy are an important reason for greenhouse gas emissions and environmental degradations. The countries having the largest share in international trade has emerged as the largest contributor to CO_2 emissions (British Petroleum, Statistics, 2023). United Nations Environment Programme (2020), in its observations, reveals that there is a rise in the atmospheric temperature by more than 3°C. It has been said that there has been an increase in methane and nitrous oxide over the years. Further, it has been said that the high increase in the temperature is likely to bring catastrophic weather events, ozone

layer depletion and ecosystem degradation and ultimately it will be a threat to the ecological balance. United Nations Environment Programme (2020) aims to decrease the global temperature and restrict it to 1.5°C under the Agenda-2030. It focused on an urgent need to rely on clean, green and renewable energy to save humanity and to maintain the ecological balance. Zakari et al. (2021), in a study about the association between ENR and environmental mitigation in selected OECD countries by employing the PMG-ARDL model and Dumitrescu and Hurlin test. The application of the said test reveals that ENR has a positive and significant impact on CO_2 emissions in the long run and there is a positive correlation between ENR, real GDP and per capita GDP on CO_2 emissions in the short run during the period 1985-2017. Further, the outcomes of the causality test reveal a unidirectional causality running from real GDP and GDP per capita square to CO_2 emissions in a panel of OECD countries.

1.1. Research Gap and Rationale of the Study

In the new international economic order, liberalisation, privatisation and globalisation play a crucial role across countries globally. The growing pace of international trade has been biased in favour of the developed countries. It has also been observed that it has resulted in enhancing the environmental mitigation due to the use of old techniques, over utilisation of natural resources, excessive use of energy and urbanisation etc. in the face of excessive challenges for further growth and development across the globe. The international trade has two-fold impact that is on the one hand, it enhances income, output and employment and at the same time, it generates pollution, greenhouse gas emissions, ozone layer depletion and overutilisation of natural resources and thus it poses a big threat to the sustainability of the environment. It has been empirically observed that an increase in the volume of trade has been accompanied by an increase in CO_2 emissions. The international trade should be pursued in such a way that it may result in enhancing income, output and employment without degrading the environmental quality. In such a situation, there is a need to adopt such a policy measure which has two-fold spillover effects in the economy. The various studies have observed that international trade has emerged as a significant factor in promoting growth and development in all the countries of the world. The study will be helpful for the policymakers to take necessary action and to opt for such a basket of policy mixes which may decrease CO_2 emissions on the one hand and also to accelerate the pace of growth and development with an effort for the economy to continue on the sustained growth path.

1.2. Contribution of the Study

The present study deviates from the existing study, which has used the traditional methods of panel data analysis. This study has relied on the PMG-ARDL estimator developed by Pesaran and Smith (1995) and Pesaran et al. (1999). The presence of Cross-Sectional Dependency (CSD) test and a combination of mixed order of integration enables the study to apply the PMG-ARDL to analyse the long run panel cointegration association among the selected variables in the model (Zakari et al., 2021). The uniqueness of applying the said method is that it overcomes the heterogeneity, autocorrelation and endogeneity issues very consistently and efficiently (Narayan, 2005; Ansari et al., 2023) to investigate the role of TO on environmental mitigation in the BRICS countries during the period 1990-2021. Further, the study also applied the panel DOLS developed simultaneously by Kao and Chiang (2000), to analyse the long run cointegration association among the set of variables included in the model and also to authenticate the findings of the PMG-ARDL estimator. The panel DOLS method is more powerful than the OLS and FMOLS (Kao and Chiang, 2000).

The empirical outcomes indicate the occurrence of a long-run cointegration association among the set of variables in the model. The findings confirm that Yt, TO, ENR and URB depict a positive impact on environmental mitigation in the BRICS countries. Further, FD does not show any negative impact on environmental mitigation in the BRICS countries. The short-run estimates indicate that Yt, FD, ENR and URB have a positive impact on environmental mitigation. However, TO does not depict negative impacts on environmental mitigation in the BRICS countries in the short-run.

Finally, the study validates the outcomes of the PMG-ARDL estimator and panel DOLS by applying the Dumitrescu-Hurlin test. The present study has been divided into five sections. The first section provides an introduction whereas the second section is accompanied by available recent literature reviews. The third section provides an account of the theoretical background and hypothesis of the study. The data used and model specification has been presented in section 4. Finally, the major findings and valuable suggestions for policy making has been summarised in the last section.

2. REVIEW OF LITERATURE

The number of studies is growing on the mitigation of the environment due to a change in the growth of macroeconomic aggregates. The association between Yt and environmental mitigation is best shown by the Environmental Kuznets Curve (EKC). The numerous studies on the association between Yt and environmental mitigation have observed a mixed outcome. Kahuthu (2006), in a study, observed a U-shaped relationship between Yt and environmental mitigation. Wang, et al. (2023) and Kostakis and Arauzo-Carod (2023) and in their study on the association between Yt and environmental mitigation, validated the EKC hypothesis. The empirical study on the effect of Yt, TO, tourism and CO_2 emissions in China by applying the QARDL model observed the validity of the EKC hypothesis (Sharif et al., 2020). The other empirical studies on the association between Yt and environmental mitigation by Rahman et al. 2019 for a panel of Central and Eastern European countries and Kihombo et al. (2022) for a panel of numerous West Asian and Middle Eastern countries also validated the existence of EKC hypothesis. Adebayo, et al. (2021), in their studies about South Korea have observed that CO_2 emissions increase with Yt and thus invalidates the EKC hypothesis. Rahman et al. (2021), in a study on the relationship between Yt and environmental degradation in the BRICS countries invalidate the EKC hypothesis and argue that environmental mitigation widens with economic growth. Qamri et al. 2022 and Xing et al. (2023), in their study about some of the Asian countries have not validated the EKC hypothesis. Cetin et al. (2023), in

their study, observed that environmental mitigation is reduced due to globalisation and the consumption of renewable energy in the long run while it has been observed that environmental pollution is being encouraged by economic growth and financial development. Khatlan; Alam and Javid (2012), in their study by applying ARDL and VECM techniques observed that energy consumption has no mitigating impact on CO2 emission in the short run while it has long run environmental mitigation impact of economic growth in Saudi Arabia. Alam (2022), in a study finds that energy consumption increases CO2 emissions in Bahrain.

The pragmatic studies on the impact of FD on CO_2 emissions have observed a mixed results. The study by Levine (2004), on the relationship between FD and environmental quality observed that FD reduces environmental mitigation because FD causes technological advancement and thus improves the environment. Sadorsky (2010), in his study on the relationship between FD and CO_2 emissions, justified that FD promotes research and development and improves the environmental quality. Tamazian et al. (2009), in their study on FD and environmental degradation in the BRICS countries, observed that FD improves the environment. The relationship between environmental mitigation and FD by applying the FMOLS to a panel of G-20 countries has found that FD reduces environmental degradation (Paramati et al., 2016). Abid (2017), in his study on the relationship between environmental mitigation and FD by applying the GMM method to a panel of 58 countries on the above observed facts that FD impacts on mitigation the environment reduces over time. Karlilar et al. (2023), in their study, observed that FD improves the environmental sustainability. Alam and Jamil (2016), in their study on the implication of high energy consumption by applying the Panel cointegration and Panel DOLS in GCC countries observed that high dependency on oil consumption is likely to implicate further economic growth and may raise other implications.

In contrast, several studies have however found that FD causes environmental mitigation. Zafar et al. (2019), in their study on the relationship between FD and environmental mitigation, observed that FD enhances environmental mitigation. Mesagan and Olunkwa (2020), in their study of a panel of 18 African countries on the above observed fact that FD improves environmental quality in the short-run while it indicates a negative impact in the long run. Qalati et al. (2021), in their work on FD and environmental mitigation, observed that it FD enhances environmental mitigation.

1. There exists a divergent opinion regarding trade openness whether it leads to environmental degradation or not. Wang et al. (2013), in their study about Japan, observed that globalisation significantly contributes to an improvement in environmental quality. Shahbaz et al. (2013a; 2015), in their work on economic growth, trade and investment observed that globalisation causes environmental degradation via economic growth and further observed that globalisation increases CO_2 emissions. Wen et al. (2021), in their study, observed that globalisation diminishes environmental quality in African countries. Wang et al. (2019), in their study in a panel of developing and developed countries, observed that social and cultural globalisation reduces CO_2 emissions in the developed countries and increases CO_2 emissions in the underdeveloped countries. Warsame et al. (2023), in their study in Somalia observed that TO improves environmental quality in the short run and degrades environmental quality in the long run. Aladejare (2022), in a panel study of 5 top African countries in terms of GDP per capita observed that globalisation improves the environmental quality. Ahmad et al. (2023), in their study in a panel of OECD countries find that globalisation causes environmental mitigation. Balsalo-Bre-Lorente et al. (2023), in their study about selected Central and Eastern European countries, observed that globalisation causes environmental mitigation.

The empirical studies on the linkages between ENR and environmental mitigation has contradictory observations. The findings shows that more than 80% of the ENR and CO_2 emissions are in the G20 countries which are also the major contributor in CO_2 emissions. Qalati, et al. (2021), in their study on the relationship between ENR and CO_2 emissions in G20 countries observed that renewable ENR increases well-being whereas non-renewable ENR degrades subjective wellbeing for the period 2006-2021. Esther et al. (2021), in their study on the relationships between ENR and CO_2 emissions in MINT countries by applying the PMG-ARDL technique and Granger causality test find a long run nexus among the variables for the period 1971-2017. They have observed that a 1% increase in primary ENR causes a 0.42% increase in environmental quality degradation in the long run while in the short run is insignificant. The study has also observed a unidirectional causality flowing from Yt, ENR, URB and ecological footprint and from economic growth to biodiversity. Akhmat et al. (2014), in their study on the association between ENR and ecological pollutants in a panel of SAARC countries, observed that ENR serves as a driver to enhance ecological pollution for the period 1975-2011. Mobeen and Mushab (2017), in their study on the relationship between ENR and CO_2 emissions in a panel of SAARC countries by applying the FMOLS and DOLS method observed that ENR tends to increase environmental degradation. Apergis et al. (2010), in their study about 19 developing and developed countries observed that nuclear ENR decreases CO_2 emissions in the short run and renewable ENR improves the environmental quality.

The urbanisation and environmental degradation are linked by the use of energy consumption. Further, ENR increases with an increase in the pace of urbanisation. Al-Mulali and Ozturk (2015), in their study of a panel of 14 countries in the Middle East and North African countries observed that urbanisation effects negatively environmental quality. Chen; Wang and Zhong (2019), in their study on the relationship between Yt, URB and CO_2 emissions observed that an increase in URB leads to an increase in ENR affects the environmental quality. Saidi and Mbarek (2017), in a study on the relationship between URB and environmental mitigation observed that URB reduces environmental degradation. Ali et al. (2017), in their study in Singapore, observe that an increase in urbanisation enhances environmental degradation. Shahbaz et al. (2014), in their study about UAE observed that urbanisation mitigates the environmental quality.

He at al. (2021), in their study about Mexico by applying the ARDL model observed that globalisation and financial innovation enhances

quality of the environmental while ENR and Yt degrades quality of the environmental and further TO doesn't depict negative impact on the environmental quality. Jebli et al. (2016), in their study on the relationship among monetary development, non-sustainable sources of power utilisation, CO_2 emissions and TO in 25 OECD countries by applying Granger causality test, FMOS and DOLS during 1980-2010 observed an inverted U-shaped EKC curve and concluded that non-renewable ENR causes CO_2 emissions and TO causes through renewable ENR diminishes environmental quality.

3. THEORETICAL BACKGROUND AND HYPOTHESIS

The environmental sustainability as the major concerned areas which has been widely studied in recent times. Environmental Kuznets Curve (EKC) hypothesis is related to U-shaped, inverted U-shaped (greenhouse gas emissions, global warming, ozone layer depletion, acid rain) ecological imbalance and its overall impacts on the ecological balance, human health, productivity and overall sustainability of the environment has been much emphasized as the areas of the study. The existing studies on the association among CO_2 emissions, Yt, ENR, TO along with other macroeconomic variables have grown over the years (Grossman and Krueger 1991; Panayotou, 1993; Yang et al., 2020; 2021; Danish et al., 2019; Alola et al. 2019; Destek and Sinha, 2020; Kayani et al., 2020 and Jahanger, 2021). Environmental sustainability emerges as an important area of concern and there has been much talk about relying on clean, green and renewable energy to maintain the ecological balance within manageable limits. United Nations conference (2012, 2015) related to sustainable development, green and clean energy and efforts to achieve 17 goals by 2030 reflects its growing importance for sustaining ecological balance. Lamini (2021), in their work on the association among innovation, TO and CO_2 emissions in Africa by applying the panel fixed effects and GMM method for the period 1990-2016 observed that U-shaped EKC hypothesis in 4 out of a panel of 9 African countries. Shahbaz et al. (2019), in their study, observed that global warming is being caused by greenhouse gas emissions. The excessive exploitation of natural resources and high pressure on Yt and development cause environmental issues (Liang et al., 2019). The trade openness has mixed effects on environmental sustainability (Essandoh et al., 2020). In the availability of theoretical and empirical studies related to the direct and indirect effects of TO and CO_2 emissions, the literature guides the study to set the following hypothesis.

3.1. Hypothesis of the Study

H_1: Trade Openness Causes Environmental Degradation

The international trade facilitates an important role in promoting the growth and development of the world economy. Khan et al. (2022), in a study on the relationship between export and other variables and its impact on CO_2 emissions in G-7 countries for the period 1990-2018 observed that export causes CO_2 emissions. The studies have observed that widening the trade base involves more energy consumption which serves as an important source of CO_2 emissions (Shabaz et al., 2017). China which has a large international trade base became the largest contributor to CO_2 emissions (BP, Statistics of World Energy, 2023). Zhang et al. (2018), in their study on the association between TO and CO_2 emissions in a panel of newly industrialised countries, observed that TO negatively and significantly affects CO_2 emissions. Destek et al. (2016), in their study on the relationship between TO, ENR and CO_2 emissions observed that increased ENR increases CO_2 emissions while an increase in trade decreases CO_2 emissions. Given the divergent observations regarding the relationship between TO and CO_2 emissions, present study aims to examine the impact of TO on environmental quality in the BRICS countries.

H_2: The interaction of economic growth, financial development, energy consumption and urbanisation improve the environmental quality.

It has been seen that the growth of different macroeconomic variables has a significant and insignificant impact on environmental quality. The aim is to maintain the ecological balance, sustainable environment and greenhouse gas emissions within manageable limits. United UNCSD, 2012 and United Nations (2015) set an Agenda - 2030 to reduce CO_2 emissions by employing the growth of different macroeconomic variables judiciously. Some existing studies on the relationship between Yt and environmental mitigation observed a U-shaped and inverted U-shaped relationship (Kahuthu, 2006; Kostakis, 2006; Arauzo-Carod, 2023; Wang et al., 2023; Rahman et al., 2019; Kihombo et al., 2022; Adebayo et al., 2021; Qamri et al., 2022; Xing et al., 2023). The study on the association between FD and environmental quality has observed that FD improves environmental quality (Levine, 2004; Tamazian et al., 2009; Sadorsky, 2010; Paramati et al., 2016; Abid, 2017; Karlilar et al., 2023). Most of the studies on the association between TO and environmental quality observed that TO decreases environmental quality (Shahbaz et al., 2013b; 2015; Wen et al., 2021; Wang et al., 2019; Warsame et al., 2023; Ahmad et al., 2023; Balsalo-Bre-Lorente et al., 2023). The existing studies on the association between ENR and environmental quality opined that ENR degrades environmental quality (Qalati, et al., 2021; Esther et al., 2021; Akhmat et al., 2014; Mobeen and Mushab 2017; Apergis et al., 2010). Further, the existing study on the association between URB and CO_2 emissions observed that URB causes environmental degradation (Al-Mulali and Ozturk, 2015; Saidi and Mbarek 2017; Ali et al., 2017; Shahbaz et al., 2014). The findings call for a judicious growth of the macroeconomic aggregates and to rely on sustainable growth, technological innovation, financial innovation, clean and green energy, renewable energy, trade openness and sustainable urbanisation in such a way that ecological balance can be maintained. Following the empirical studies, the study investigates whether the interaction of Yt, FD, ENR and URB have a net significant and insignificant effect on the environmental quality and also suggests the policy measures in the BRICS countries.

4. DATA AND MODEL SPECIFICATION

We examine the long run association among the environmental mitigation, real GDP per capita, financial development, trade openness, energy consumption and urbanisation in a panel of BRICS countries during 1990-2021. In the sustainable

environmental literature, the findings that environmental quality is being affected by the growth of national income, financial development, trade openness, energy consumption and urbanisation. The earlier studies have observed that the growth of national income, financial development, trade openness, energy consumption and urbanisation exert a significant influence on environmental quality. Relying on the theoretical and empirical foundations, the association among environmental quality, GDP per capita, financial development, trade openness, energy consumption and urbanisation can be expressed as:

$$CO2_t = f(YP_t, FD_t, TO_t, ENR_t, URB_t)$$

Where, ($CO2_t$) indicates the environmental degradation, (YP_t) shows the real per capita GDP and (FD_t) shows the financial development, (TO_t) trade openness, (ENR_t) energy consumption and (URB_t) urbanisation.

In a cross-sectional approach, the model in a logarithmic base can be formulated as follows:

$$LnCO2_{it} = \alpha_{oi} + \text{LnYP}_{it} + \alpha_2 \text{LnFD}_{it} + \alpha_3 LnTO_{it} + \alpha_4 LnENR_{it} + \alpha_5 \text{LnURB}_{it} + \varepsilon_t \quad (1)$$

Where, α_o is constant and $\alpha_1 \ldots . \alpha_5$ depicts the parameters estimated, 'I' depicts the cross-sectional data about the panel of BRICS countries and "*t*" represents the time period in the model. The term ε_t depicts the random disturbance term which is assumed to be normally. Further, the respective regressors depicts their impact on the regressed variable in the model.

4.1. Data

The data on CO_2 emissions million tonnes (mt) has been taken from the IEA, database, OECD, 2023 and BP, Statistics, 2023). The data on real Yt measured at US $ at constant 2015 prices, data on FD (domestic credit to the private sector by banks as a per cent of GDP), data on ENR and data on URB (urban population growth as a percent of annual population) has been taken from WDI, World Bank's database, 2023. The data has been considered for the period 1990-2021 for a panel of BRICS countries namely Brazil, Russia, India, China and South Africa. These countries were chosen because they are growing fast and developmental work is taking place on a larger scale. The pace of growth, development and overall socio-economic transformation also involves environmental hazards such as rising CO_2 emissions, ENR and URB etc cause a threat to the sustainability of the environment which may cause health hazards and may bring social unrest and ecological imbalance.

4.2. Heterogeneous Panel Unit Root

The study initially starts with exploring the investigation regarding the existence of a panel co-integration by investigating a panel unit root of the data included in the model. The study relied upon Levin et al. (2002) and Im, Pesaran and Shin (2003), unit root test to find out the panel unit root (Hlouskova and Wagner 2006; Narayan and Smyth 2007). The said tests follow the properties of a normal distribution and propose that ρ_i are identical and negative. The uniqueness of the use of Im, Pesaran and Shin (2003) test is that it allows for a separate estimation for each cross-section having a separate specification of the parametric values and the residual variance. The lag lengths in the model are based on the SIC lag length criteria (Asterious and Hall, 2006). The said test is suitable even when size of the sample is small and that too without large distortions (Kao and Chaing, 2000). The said ADF test can be expressed as:

$$\Delta Y_{it} = \alpha_i + \rho_i Y_{it-1} + \sum_{j=1}^{n} \delta_j Y_{t-j+\beta_{it}+\varepsilon_t}$$

The test assumes that there should be identical 't' for all the cross sections. This shows the average of each ADF t-statistics for testing that $\rho_i = 0$ for all the cross sections. $\bar{t} = \frac{1}{N}\sum_{i=1}^{N} t_{pi}$. Further, Im, Pesaran and Shin (1997) stated that t-bar provides better outcomes even when the N and t are small.

4.3. Cross-Sectional Dependency Test and PMG-ARDL Estimator

The study applied the Pesaran CSD test and the Pesaran Scaled LM test to trace the presence of CSD in a panel of BRICS countries. The presence of CSD and a combination of mixed order of integration will enable the study to apply the second generation PMG-ARDL technique to estimate the long-run panel cointegration relationship among the selected variables in the model (Zakari et al., 2021). The uniqueness in applying this method is that it overcomes the heterogeneity, autocorrelation and endogeneity issues very consistently and efficiently (Narayan, 2005; Lbhagu and Olawole, 2019; Ansari et al., 2023). Furthermore, the PMG-ARDL estimator is found to be efficient even with a small sample. Further, the standard t-distribution and F-tests are also consistent with the long run parameters (Pesaran, et al., 1999).

$$\Delta LnCO2_{it} = b_i \left(LnCO2_{i,t-1} - \Delta_i n_{i,\,t-1} \right) + \sum_{j=0}^{y-1} \sigma_{ij} \Delta n_{i,\,t-1} + \sum_{j=0}^{x-1} \epsilon_{ij} \Delta n_{i,\,t-1} + \Delta_i + \mu_{it} \quad (2)$$

Here the dependent variable CO_2 represents the carbon dioxide emission million tonnes and where ($LnCO2_{i,t-1} - \text{ɗ}_i n_{i,t-1}$) represents the long run deviation and b_i indicates about ECT which is basically the speed of adjustment which are normally negative and significant. Further, vectors namely € and ɗ represents the short-run and long-run coefficients in the model. Likewise, the ɗ rerefers to the unobserved time-invariant and indicates about the country specific effect and lastly μ_{it} represents the LnYt, LnTO, LnFD, LnENR and LnURB as an important factor which effects $LnCO_2$ emissions.

4.4. Panel Long-run Cointegration Relationship

The study after establishing the presence of a long-run panel co-integration relationship, applied the panel DOLS to analyse the long-run cointegration association among the set of variables included in the model.

5. EMPIRICAL RESULTS

Table 1 presents the results of Levin et al. (2002) and lm Pesaran and Shin (2003), panel unit root test of the variables selected in

Table 1: Panel unit root test result

Variables	Levin, Lin and Chu levin, test	First difference	Lm Pesaran and Shin ADF-test	First difference
$LnCO_2$	−1.64 (0.050)*	1.658 (0.049)*	−0.0560 (0.289)	2.895 (0.002)**
LnLYt	−2.11 (0.0173)**	3.063 (0.001)**	1.107 (0.866)	3.684 (0.000)***
LnLFD	−2.001 (0.023)	4.020 (0.000)***	−2.576 (0.005)**	5.594 (0.000)***
lnLTO	−2.176 (0.0148)***	12.523 (0.000)***	−11.8374*** (0.000)	10.368 (0.000)***
lnLENR	−1.756 (0.040)	3.406 (0.000)***	0.000 (0.500)	3.968 (0.000)***
LnURP	−1.171 (0.121)	1.735 (0.958	2.572 (0.995)	2.915 (0.998)

***, **and *indicates variables are significant at 0.01%, 0.05% and 0.010%

Table 2: Cross-section dependence (CSD) test

Test	Statistic	Prob.
Breusch-Pagan LM	45.796***	0.00
Pesaran scaled LM	8.004**	0.00
Pesaran CD	3.903*	0.00

***, **and *indicates variables are significant at 0.01%, 0.05% and 0.010%

Table 3: Descriptive statistics of the macroeconomic variables

	$LnCO_2$	LnYt	LnFD	LnTO	LnENR	LnURP
Mean	7.125	8.230	3.897	3.636	6.099	3.985
Median	7.207	8.675	3.956	3.740	6.223	4.109
Maximum	9.390	9.326	5.209	4.706	8.213	4.470
Minimum	5.429	6.271	1.484	2.718	4.531	3.241
Std. Dev.	1.080	0.860	0.684	0.393	0.980	0.399

the model. The outcomes of the unit root test mentioned above indicates that some of the variables are stationary at the level and some others at their first difference.

The study also applied the CSD test developed by Pesaran and scaled LM test developed by Pesaran (2004) to trace the pace of CSD in a panel of BRICS countries (Zakari et al., 2021). The outcome of the test is presented in Table 2, depicts that null hypothesis of no CSD is rejected in BRICS countries and accepts the alternative hypothesis of the presence of CSD in BRICS countries at 0.01%, 0.05% and 0.10% respectively.

The Table 3, depicts the descriptive statistics of the selected variables in the model. The outcomes show that mean value of the series varies between 3.636 and 8.230 where the lowest value is LnTO and highest value is for LnYt. The standard deviation with lowest values is 0.393 for LnTO while highest standard deviation is 1.080 for $LnCO_2$.

The Table 4, depicts the degree of association based on the correlation matrix among the selected variables in the model. The correlation matrix in the table shows that almost all the variables shows that there is a positive correlation between LnTO and $LnCO_2$ which is consistent with the findings of Cetin et al. (2023). Further, LnFD, LnENR is positively correlated with $LnCO_2$ while LnURP is negatively correlated with $LnCO_2$.

The outcome of the panel unit root test of the selected variables LnCO2, LnYP, LnFD, LnTO and LnURB enable the study to apply PMG-ARDL model in order to test the presence of the cointegration relationship among the variables in the model.

Table 4: Correlation analysis

Variables	$LnCO_2$	LnYt	LnFD	LnTO	LnENR	LnURP
$LnCO_2$	1.0000					
LnYt	−0.0927	1.0000				
LnFD	0.2929	0.1303	1.0000			
LnTO	0.3984	0.2321	0.0289	1.00		
LnENR	0.9722	−0.0792	0.2644	0.2489	1.00	
LnURP	−0.3252	0.9415	−0.1187	0.0921	−0.2778	1.00

Table 5: Long-run estimates based on PMG-ARDL estimator

Variables	Coefficients	Std Error	P-statistics
Long-run estimates			
LnYt	0.107	0.066	0.108
LnFD	−0.036	0.025	−0.144
LnTO	0.036	0.023	0.126
LnENR	0.947	0.055	0.000***
LnURP	0.189	0.169	0.267
ECM	−0.528	0.143	−0.000***
Short-run estimates			
lnYt	0.135	0.089	0.131
lnFD	−0.004	0.021	0.852
lnTO	0.013	0.021	0.520
lnENR	0.269	0.096	0.006**
lnURP	3.257	7.619	0.670

***, **and *indicates variables are significant at 0.01%, 0.05% and 0.010%

Table 6: Long-run estimates based on DOLS estimator

Variables	Coefficients	Std Error	P-statistics
LnYt	0.126	0.045	0.006
LnFD	−0.052	0.0157	0.002
LnTO	−0.001	0.027	0.959
LnENR	0.930	0.049	0.000
LnURP	0.226	0.139	0.110
R – squared=0.999 → Mean dependent var=7.141			
Adjusted R squared=0.999 → S.D. dependent var=1.034			
S.E. of regression=0.019 → Sum squared residual=0.021			
Long-run variance=0.000			

***, **and *indicates variables are significant at 0.01%, 0.05% and 0.010%

5.1. Results of PMG-ARDL

The study after tracing the presence of a cointegration relationship applied the PMG-ARDL test (Zakari et al., 2021) which is shown in Table 5. The long-run estimates confirms that LnYt, LnTO, LnENR and LnURB have a positive impact on environmental mitigation in a panel of BRICS countries. However, LnENR depicts a positive and significant impact on environmental mitigation in the BRICS countries. Further, LnFD does not show any negative impact on environmental mitigation in a panel of BRICS countries. The ECM term which represents the speed of adjustment as negative and significant depicts that 53% of the variation will be corrected

within the year. The short run estimates indicate that LnYt, LnTO, LnENR and LnURB have a positive impact on environmental mitigation in a panel the BRICS countries. Moreover, estimates of the energy consumption shows that it has positive and significant impact on environmental mitigation in BRICS countries. However, LnTO does not depict a negative impact on environmental mitigation in the short-run.

Further, the study applied DOLS to trace the long run co-integration relationship among the variables in the model and the estimated outcomes are presented in Table 6 (Zakari et al., 2021). The estimated outcomes indicate LnYt, LnENR have positive and significant impact on mitigating environmental sustainability while LnURB shows a positive impact on mitigating environmental quality in a panel of BRICS countries. Further, the estimated outcomes show that LnFD and LnTO does not show any negative impact on mitigating environmental quality in the BRICS countries during the period 1990-2021.

5.2. Dumitrecu-Hurlin Causality Test

The study in order to trace the direction of relationship also applied the Dumitrecu-Hurlin causality (2012) test and outcomes are shown in the Table 7. The said test applies classical and bootstrap causality analysis and also considers the CSD test (Cetin et al., 2022). This approach is based on the regression coefficients.

$$x_{it} = \alpha_i + \sum_{i=1}^{K} \lambda^k{}_i x_{i,t-k} + \sum_{j=1}^{n} \delta^k{}_i y_{i,t-k+\varepsilon_{i,t}}$$

The application of Dumitrecu-Hurlin (2012) causality test results in and statistics and its computed value is being compared with bootstrapped critical values provided by Dumitrecu-Hurlin (2012) causality test. The outcome of the study depicts that causality flowing from LnYt to $LnCO_2$ and likewise causality also flowing from $LnCO_2$ to LnYt and establishes a bidirectional causality (Aslam et al., 2021). However, this observation is in contrast to the observations that LnYt causes environmental mitigation and there is a one way directional causality (Abbasi et al., 2022; Dogan and Seker, 2016).

The outcomes of the Dumitrecu-Hurlin causality test depicts that LnTO causes environmental mitigation and it establishes a one-way causality. This outcome is being supported by Aslam et al., 2021; Jahanger et al., 2022b; Aladejare, 2022. However, while Chien et al. (2021) have not observed any causal relationship between them. The outcomes reveal that there is a two-way directional causality between LnFD and environmental mitigation. This is being supported by the earlier studies who has established a two-way causality (Acheampong, 2019; Nasir et al., 2019; Oztruct et al., 2023). However, Cetin et al. (2022) and Habiba et al. (2023) finds a bidirectional causality between the LnFD and $LnCO_2$ emissions.

The outcomes of causality test depict that LnENR does cause environmental mitigation. This is consistent with the results that LnENR and output causes $LnCO_2$ emissions (Chontanwat and Jaruwan, 2019).

Further the findings do not indicate any causality between LnURB and $LnCO_2$ emissions which is constant with the findings (Cetin et al., 2023). However, in contrast Zhao and Yang, 2020 observe a two-way causality between LnURB and $LnCO_2$ emissions. Salahuddin et al. (2019), observe a one-way causality flowing from LnURB to $LnCO_2$ emissions.

6. CONCLUSION AND POLICY RECOMMENDATION

Since the inception of liberalization, privatization and globalization world economy has recorded a massive change in the pattern and distribution of income, output and employment. This has led to an increase in the internationalization of the world economy which is accompanied by an increase in the magnitude of international trade and flow of MNCs along with technical and financial collaborations. This has resulted in the high LnENR, over exploitation and misutilization of resources in the country. This puts pressure on the environmental quality in the concerned countries. This has provided an important impetus to study the assoiation between LnTO and environmental mitigation. This study makes an attempt to empirically examine the relationship between LnTO and environmental mitigation by controlling the variables such LnYt, LnFD, LnENR and urbanization (LnURB) for the period 1990-2021. In this analysis, Levin, Lu and Chu, Levin Lu and lm Pesaran and Shin unit root analysis has been applied. The study also applied the Pesaran CSD test to trace the presence of CSD among the selected variables in the model. The panel PMG-ARDL technique and panel DOLS technique have been used to estimate the long term and short term cointegration

Table 7: Dumitrecu-Hurlin causality test

Hypothesis	W Stat	Z-bar Stat	Bootstrapped P-value	Results
lnYt #>$lnCO_2$	5.419	3.059***	0.002	lnYt ⟷ $LnCO_2$
$lnCO_2$ #>lnYt	13.381	10.565***	0.000	
lnFD #>$lnCO_2$	4.48	2.174**	0.03	lnFD ⟷ $LnCO_2$
$lnCO_2$#>LnFD	5.538	3.172***	0.002	
lnTO#>$lnCO_2$	5.466	3.104***	0.002	lnTo ⟶ $LnCO_2$
$lnCO_2$#>lnTO	8.291	5.766	8.379	
lnENR#>$lnCO_2$	3.993	1.715	0.086	
$lnCO_2$#>lnENR	7.87	5.37	8.789	
lnURP#>$lnCO_2$	9.333	6.749	1.345	
$lnCO_2$#>lnURP	3.393	1.149	0.251	

***, **, *indicates significant at 0.01%, 0.05% and 0.010% levels respectively

relationship among the variables in the model. Finally, the study applied the Dumitrescu-Hurlin panel causality technique to trace the direction of causality among the selected variables included in the model.

The estimated outcomes reveal the presence of CSD among the set of variables included in the model. The outcomes of the PMG-ARDL model technique reveal that LnYt, LnTO, LnENR and LnURP have positive impact on CO_2 emissions in the long run in a panel of BRICS countries. In the short run, LnFD and LnTO does not indicate negative impact on environmental mitigation in the BRICS countries. The outcomes of Panel DOLS indicate that LnYt, LnENR and LnURP reveal a positive impact on the environmental mitigation in a panel of BRICS countries. The estimated outcome of Dumitrescu-Hurlin test reveals that unidirectional causality is flowing between LnYt and $LnCO_2$ emissions and between LnFD and $LnCO_2$ emissions. The outcome also reveals that one-way causality flowing from LnTO to $LnCO_2$ emissions in the BRICS countries. These outcomes indicate empirical evidence that LnTO does negatively affect the environmental quality in the BRICS countries.

To reverse the role of LnYt, LnTO, LnENR and LnURP induces environmental degradation enable the study to make the following recommendations. Firstly, it has been seen that trade openness facilitates the enhancement of the magnitude and volume of trade. The increasing pace of export and of course the import substitution measures put pressure on the available natural resources which are overexploited and even misutilised. This points out that there should be a concern towards that while dealing with trade requires to have an extra caution for the environmental protection. Secondly, it has been observed that LtYt enhances environmental mitigation which is responsible for greenhouse gas emissions, health hazards and unsustainability of the environment which needs to be based on environmental concern. The appropriate use of technology and a rise in the GDP per capita has to be taken care of the environmental concerns. Further, an increase in the dimension of trade enhances the use of energy consumption which is being used by fossil fuels etc led to enhance $LnCO_2$ emission that needs to be replaced by renewable energy, safe and clean energy which will reduce the degradation of environmental quality. It has been seen that urbanization and improvements in infrastructural facilities and developing smart cities enhances $LnCO_2$ emissions which needs to base on the environmental concern. This requires an equal amount of compensation by forestation and renewable resources and dependency should be made on safe, clean and renewable sources of energy for developmental projects. Further, it has been practiced that financial innovation induces us to avail better energy and use of such techniques which are environmentally friendly. This requires an effort made by the government with certain concessions for accessing environmentally friendly technologies.

The study in spite of its effort has some limitations which are beyond the scope of the study. The study considers $LnCO_2$ emissions as a major cause of environmental mitigation and not taken other factors which do affect the environmental quality. The study considers only a panel of five BRICS countries and not taken into account the other emerging countries. Further, the study has not considered the renewable energy and use of green energy due to the lack of proper data. This study provides a scope for further studies which incorporates the other emerging economies, use of renewable energy, green energy and use of better technology.

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