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Determinants of CO2 emissions in the BRICS economies: The role of partnerships investment in energy and economic complexity

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ABSTRACT

The anthropogenic implications of energy consumption, real income level, and natural resources abundance have been well documented in the environmental economics literature. However, given the uniqueness of many economies i.e., partnerships investment in energy and economic complexity around the globe, it is imperative to investigate the nexus between the outlined variables in a carbon-income framework. To this end, we leverage on second- generational panel methods for its superiority over first-generation model over annual frequency data from 1990 to 2018 for the case of BRICS countries. Empirical findings show that positive changes in trade openness and economic complexity stimulate environmental quality. On the contrary, economic growth, natural resources and public-private partnership contribute to environmental degradation. Based on these results, new insights are obtained for the policymakers, and policies are recommended to develop the environmental quality in BRICS economies.

Introduction

Undoubtedly, one of the most prominent troubles of humankind in the 21st century is environmental degradation [1]. Global warming adversely affects the living conditions of living things with the increase in the number of gases in the atmosphere. According to the IEA [2] report, an estimated 6.5 million deaths each year are connected to air pollution, and if action is not taken urgently, deaths will increase significantly in the coming years. Moreover, the World Health Organization (2019) claims that air pollution is expected to bring an additional 250.000 deaths per year between 2030 and 2050. One of the important reasons of environmental degradation that occurs with climate change is the excessive number of gases released into the nature. Carbon dioxide (CO_2 emission is an important cause of climate change [3,4]. According to the World Bank [5], CO_2 emissions in the world increased from 9420,523 kt in 1960 to 35,998,929 kt in 2016.

What are the reasons for the increase in emission amount so much? Why are emissions constantly increasing despite the negative impact of air pollution on living things? Politicians, researchers, independent organizations and global organizations have been searching for answers to these questions from past to present. For example, global climate conferences (Stockholm Climate Conference, Kyoto Protocol and Paris Agreement etc.) have produced solutions to answer the above questions and showed individual goals to countries. However, World Bank Indicators database [5] show that countries are far from meeting their emission targets. Moreover, Nachmany and Mangan [6] showed that only 15 of the 195 countries that are party to the Paris Agreement fully comply with the agreement. The term economic growth paradigm can be used to explain this situation of countries [7]. Because Caglar (2020) states that countries aiming to grow should use energy for service and production. Especially these countries cannot invest in renewable resources due to insufficient infrastructure and income. Therefore, they cannot give up fossil resources necessarily. However, in the last two decades, new and alternative concepts such as low-carbon economy, sustainable growth, win–win projects and green growth continue to be present in the literature. In September 2015, the “2030 Agenda for Sustainable Development” was created by the United Nations. At the heart of this agenda are the Sustainable Development Goals (SDGs), which mean preventing poverty, targeting sustainable growth and minimizing environmental damage, now and in the future (SDGs-13). The concept of green growth is directly related to sustainable growth [8]. At the same time, while a win–win strategy generally points to

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public–private partnership (PPP), it contributes to the green growth targets of countries [9]. A variety of challenges arise for economies seeking to move towards the SDGs target and green growth. The dilemma here is that while governments increase their clean energy investments, on the other hand, they need to reduce their energy investments that cause heavy pollution. But steady increases in energy demand and scarce resources of governments direct policymakers to regional communities and the private sector in energy production [10]. Carbonara and Pellegrino [11] states that the private sector can play a critical role for energy efficiency. In addition, Agrawala and Fankhauser [12] point out that the private sector's cooperation with the public sector in combating climate change will yield effective results. In this context, cooperation is important for both the public and private sector for the following reasons:

- public sector: constantly increasing energy demand, limited capital, and willingness to transition to a green economy
- private sector: sharing risks, tax exemption, various subsidies and high technology manufacturing

A faster transition to green growth can be made with PPP in energy generation [13]. In addition, energy efficiency and cost reduction may occur with the stabilization in the energy sector [14]. As a result, the provision of energy production through PPP means that environmental transformation also takes place over time.

Another emerging environmental concept is economic complexity index (ECI), which is a size of economic development and defines the grade of knowledge and skills required in the output of exported goods. The ECI is proposed by Hidalgo and Hausmann [15], and they develop a scientific method of how to measure the capabilities required for export. To put it more clearly, ECI expresses the structural change, technical knowledge, skills and qualifications in the producing economy [16]. Thus, as the country's economy increases exports day by day, more sophisticated products are obtained by increasing their knowledge and skills in production. In this context, it can be stated that ECI also contributes to the progress of the country's economy. It is inevitable to expect a structural transformation in production with more sophisticated information [17]. When viewed from this perspective, it can contribute to explaining the link between environmental deterioration and economic development proposed by Grossman and Krueger [18]. They state that environmental corruption improves in the first stage of economic progress and that environmental degradation decreases when a particular income level is reached. Therefore, as the ECI increases in the host economy, it can be expected that environmental degradation will decrease. Because with the increase in the ECI, research and development activities and skills increase and clean technologies and environmentally friendly production are started [19]. As a result, it is important to detect the role of ECI in reducing environmental degradation.

BRICS[1] economies are the largest of the middle-income countries and, as a group, account for more than a fifth of the world economy [20]. Moreover, the BRICS countries have made significant progress in economic growth in recent decades. According to New Development Bank [21], in 2016, the group's combined economic output rose to about 22 percent of global GDP, compared with 11 percent in 2005. As of today, the BRICS combined GDP (based on Purchasing Power Parity) is greater than the G7. Thus, along with rapid industrialization, BRICS countries continue to be an important driving force of the world economy. Due to fast economic progress in the BRICS countries and considering their high population, their increase in energy consumption is inevitable. The source of about 40% of the world's energy consumption is the BRICS countries, and a large part of the global CO_2 emission from this consumption are their responsibility [22]. In this regard, the BRICS countries accounted for 41% of global CO_2 emissions before 2017 [23], demonstrating that they are globally important emitters.

Emissions in BRICS countries may have two other important causes, namely natural resources and trade openness. Fossil-sourced natural resources are one of the important determinants of CO_2 emissions [10,24–26]. Because the increased consumption of natural resources due to agriculture, mining activities and deforestation may adversely affect the air quality. Also, BRICS countries are wealthy in natural resources; for instance, 20% of the globe's resources stem from Russia, which contributes 97.7% to its local affluent [27]. Additionally, natural resource activities compose from major part of the economic action in BRICS - between 3 and 15% of GDP and a significant origin of export earnings for all economies except for China [28]. Thus, it is seen that natural resource wealth has an important place economically in BRICS. On the other hand, the share of BRICS in global commerce enhanced considerable from 3.6% in 1990 to 15% in 2010. All trade (export and import) activities currently reach $ 5.9 trillion [29]. In this regard, international commerce acts a very important part in the local economy and therefore has a profound effect on emission level [30,31]. When the environmental economics literature is examined, it is seen that the effect of trade on emissions is not clear. Some studies provide evidence that the impact of trade on emissions is positive [32–34]. On the other hand, some studies show that trade activities have an improving effect on environmental quality [35–37]. Basically, it is known that the effect of trade on the environment occurs in three (scale, technique and composition effect) different ways. In the scale effect, increases in trade activities increase emissions because they cause an increase in energy consumption. The technical effect states that the acceleration in trade activities facilitates the transfer of advanced and green technologies that reduce pollution. Finally, the composition effect, trade activities contribute to environmental pollution due to poor environmental regulations in the first stage of growth. But after growth reaches a certain level, strict environmental policies emerge. As a result, there is an indirect increase in environmental quality.

Furthermore, the possible contribution of this paper to the current environmental economics literature is as follows: i) this study attempts to bring a new breath to CO_2 emission modeling in BRICS countries, one of the leading roles of climate change, by using PPP and ECI variables. When modeling environmental degradation, the existing environmental economics literature does not consider PPP in energy production and ECI variables at the same time. Unlike previous initiatives, we are investigating countries' CO_2 emissions, PPP and ECI status for the first time in BRICS countries using the superior panel data methods. ii) many studies ignore natural resources and trade openness variables when analyzing BRICS countries, and thus the problem of omitted variable bias arises. By examining the effects of these variables both theoretically and empirically, we map their possible roles in reducing CO_2 emissions, iii) furthermore, this article specifically addresses the potential cross-sectional dependence (CSD) and slope heterogeneity problem to arrive at, efficient, consistent and unbiased estimates. Studies of this sort is timely and worthwhile in an era for alternative energy sources and environmental sustainability targets across the globe. Thus, our study will serve a policy document for BRICS government officials and other blocs in the drive for green energy targets amidst economic growth paths.

Empirical findings provide evidence of cross-section dependence and slope heterogeneity. While natural resources and economic growth increase environmental pollution, trade openness increases environmental quality. One of the variables that this study focuses on is economic complexity. Economic complexity helps improve environmental quality. On the other hand, PPP, one of our focus variables, contributes to environmental degradation. In contrast to Shahbaz et al. [9], which examined only China, we found relatively little impact of PPP on environmental degradation. When the PPP budgets of the BRICS countries are analyzed, the least investing country is China [5]. Therefore, it is seen that other BRICS countries are important for PPP. This study offers

[1] Brazil, Russia, India, China, and South Africa

policy recommendations to shed light on the environmental regulations of the BRICS economies.

The remainder of this paper follows as section 2 introduces the review of the related literature on the theme under review. Subsequently, section 3 dwells on the methodological sequence and data of the study. Section 4 focuses on the econometric findings and discussion while the concluding notes and policy direction is rendered in section 5.

Literature review

Since the groundbreaking study on the connection between energy consumption and gross national product (GNP) conducted by Kraft and Kraft [38] in US. Several other have emerged in the energy and environmental economic literature on the discourse. The first study to explore the connection between the trade-off between income level and environmental corruption is also known in the literature as Environmental Kuznets Curve (EKC) phenomenon by Grossman and Krueger [18] for the case of North American Free Trade Agreement (NAFTA). The trajectory of the literature over the years on the energy-environment-income nexus has drawn a great deal of attention from both stakeholders and researchers. These groups of studies can be classified into three divisions. The first group of literature includes strands of study that find support for the EKC phenomenon hypothesis for different blocs and single country cases such as the studies by Yilanci and Ozgur [39] for the case of G7 economies, Demissew Beyene and Kotosz [40] for East African economies and Al-Mulali et al. [41] for Kenya[2]. The second group of literature has advanced the EKC phenomenon by the addition of other macroeconomic indicators like trade openness, energy use, institutional quality, and demographic indicators like population, political regime among others [42–46]. The third divide of studies have further extended the EKC debate to the N-shaped EKC where the cubic form of income is tested on its impact on environmental quality [47–49]. The economic trajectory of economies and its anthropogenic activities pull the demand for more energy consumption and much of those demands of energy emanates from fossil-fuel base across the globe. This reinforces the assertion that energy drives economic growth [38,50]. This energy-economic relationship comes with its environmental implication and/or its damping effect on the environmental quality [44]. This assertion is reinforced in the study of Al-Mulali et al. [41] on the link between energy and economic growth in Kenya under the EKC framework. However, there exist a third group fails to find validation for the EKC phenomenon in the extant literature. That is, an increase in growth does not dampen environmental quality.

The recent strands on the literature on energy-growth and environment are in terms of modeling key macroeconomic indicators as studies that account for the mediating role of economic structure-economic complexities which explain the share of the productive capacity of economics. To this end, to explore whether economic complexities of a country affect environmental quality is explored in the literature. Doğan et al. [51] explored between ECI and the environment while controlling for the role of renewable energy consumption, total population, and economic development. The study found a significant effect on the environment across different trajectories of its economic growth is it lower-middle or higher-income divide. The study found that at low-income divide ECI dampens the quality of the environment. Thus, it is imperative for lower-income blocs to conscious of their industrial and production patterns to foster a clean ecosystem without compromise for a higher-income target. There is, the same fashion for the case of France Can and Gozgor, [52] which examines the effect of ECI on environmental quality (measured by CO_2). The study affirms the EKC phenomenon and the positive impact of conventional energy on the environmental quality. Interestingly, the study shows that an increase in the ECI in France dampens CO_2 emission i.e., improves environmental quality. This position of an inverse ECI and environment nexus resonates with the finding of Shahzad et al [53] while measuring environmental quality with a broader measure (ecological footprint) for the United States.

Shahbaz et al. [54] investigated the effect of biomass energy consumption and GDP for the BRICS economies using quarterly data from 1991 to 2015. The study incorporated trade openness in production function. The study applied the Johansen cointegration analysis between the outlined variables. Both trade and capital stock accumulation showed strong statistical evidence to increase GDP growth in BRICS over the sampled period. The Granger causality based on VECM also resonated with the causality between trade and economic growth. The study suggested from a policy lens that biomass energy was a key driver of sustainable development in BRICS. Furthermore, Sinha et al. [55] explored the effect of disaggregated energy (renewable and non-renewable energy) while accounting for the role of public sector corruption on pollution emission. The study was conducted for both BRICS and N-11 economies. The study showed that energy from fossil-fuel base dampened environmental quality for both countries. The study affirmed the N-shaped curve for both blocs while corruption degraded the environmental quality. This finding aligns with the recent outcomes of Chen et al. [56].

More recently, in BRICS, Adedoyin et al. [57] explored the links among GDP growth, CO_2 emission, and coal rent in a carbon-income function. The study accounted for the effect of regulatory quality on carbon reduction. The study used PMG methodology to explore these variables. GDP growth dampened environmental quality while renewable energy and carbon damage as a control for environmental quality in BRICS reduced pollution emission in the economies. Additionally, Nathaniel et al. [58] explored for BRICS the relationships among a renewable energy, human capital, natural resource, and ecological footprint applying FMOLS and DOLS. The study reported that natural resource and economic growth increased the ecological footprint over the sampled period. In BRICS over a sampled period, renewable energy showed desirable evidence to improve the ecosystem in BRICS. However, human capital accumulation was not yet at a desirable grade to lessen environmental pollution. The study suggested strong advocacy for clean energy by the adoption of clean technologies. Balsalobre-Lorente et al. [59] also resonated with the findings of Nathaniel et al [58] the conventional energy and human capital deteriorated environmental quality. For the case of Balsalobre-Lorente et al. [59] in BRICS, they discovered the deteriorating role of agricultural operation on pollution emission by using FMOLS and DOLS regression.

A good number of studies on the effect of macroeconomic variables on emissions in a carbon-income setting channel providing inconclusive outcomes with diversity in methodologies applied. For the case of BRICS, with the exception of the study of Shahbaz et al. [9] for China that investigated the effect of PPP in a carbon-income environment, other than the highlighted study, there exist little or no documentation on the theme that addresses the effect of PPP variable on environmental degradation in the extant literature. With sustainable energy consumption, countries can both ensure energy security and develop a green growth strategy. Despite increasing energy demand, governments have limited resources. To cope with growth and environmental challenges, the PPP model was introduced [9]. PPP refers to long-term agreements between public and private corporations to ensure the fulfillment of mandatory goods and services [24]. Improvement in energy efficiency can be achieved through PPP to achieve affordable and clean energy, which is one of the key objectives set under the SDGs. Moreover, the PPP model is often linked to sustainability [60]. As a result, it is important to establish sustainable environmental policies for BRICS, which is known to dominate global energy consumption and consists of the most emitters. Following the trajectory of literature examination, the present study contributes on the fronts:

First, this study integrates PPP, natural resources abundance, trade

[2] For more details and insights into the EKC literature see the study of Ozturk [77]

and ECI in a carbon-income function for the case of BRICS that has received fewer entries in the extant literature. The inclusion of PPP and ECI is novel for the case of BRICS and align with UN-SDG to achieve the global ambition to reduce pollution emission.

Second, this study contributes in terms of method by the adoption of second-generational modeling techniques. These techniques are superior to conventional first-generational methods namely Westerlund [61] cointegration, Cup-FM, and Cup-BC estimators, Dumitrescu and Hurlin [62] causality analysis for predictability power among the highlighted variables and circumvent for CSD and slope heterogeneity issues. Most of the available literature, unfortunately, ignores the cross-sectional dependence (CSD) and slope heterogeneity in panel data when modeling environmental degradation. CSD has an important place in the environmental economics literature. Especially when countries with the same characteristics (BRICS, G7, MENA and EU etc.) are analyzed, shocks that occur in one country in the panel dataset affect other countries as well [63]. Neglecting this assumption can give misleading results for the real world. Moreover, Andrews [64] states that ignoring CSD and slope heterogeneity in modeling CO_2 emissions may be the cause of bias and inconsistent estimates. Additionally, if there is a CSD issue in the panel data and this condition is rejected, the parameter estimators may be ineffective and inconsistent [65].

In summary, given the rich trajectory in the extant literature, the need for transition from conventional energy to renewables for a cleaner and friendly ecosystem is pertinent. To this end, the current paper explores theme for the case of BRICS which have received less documentation and account for covariates ignored in the literature such as the moderating role of total natural resources, PPP in energy production, ECI in a carbon-income function. The exploration of the additional variables also helps ameliorate for omitted variable bias problem in the econometrics modeling strategy. This study also bridges the gap of methodological advancement by the use of second generational panel estimation that circumvents cross-sectional issues and heterogeneity. Studies of this sort come in handy for proper policy construction especially in the era of global environmental awareness for environmental sustainability

Finally, this study will serve as a policy document for a government official in the trajectory to arrive at sustainable economic growth without compromise on environmental quality.

Data and method

All variables except economic complexity used in analysis were taken from World Development Indicators [5] online data base covering the available time period between 1990 and 2018 for the panel. The economic complexity index values of the countries for the same period were collected from Atlas database. The model to estimate is constructed below:

$$LnCO_{2_{it}} = \beta_0 + \beta_1 LnNR_{it} + \beta_2 LnT_{it} + \beta_3 LnPPP_{it} + \beta_4 LnY_{it} + \beta_5 ECI_{it} + \varepsilon_{it}$$
$$i = 1, \cdots, 5, t = 1990, \cdots, 2018 \tag{1}$$

In Eq. (1), $LnCO_2$ stands for natural logarithm of emissions as metric ton per capita, LnNR defines natural logarithm of the natural resources abundance measures in % of GDP, LnT points out natural logarithm of trade openness (sum of exports and imports, %GDP), LnPPP specifies natural logarithm of public–private partnership investment in energy (constant LCU) per capita, LnY represents natural logarithm of GDP (constant US$ 2010) and finally the variable ECI states economic complexity index. Because of that natural resources in a country are one of the important determinants of emissions, the expected sign of the variable LnNR is positive. That is, the higher consumption of natural resources such as agriculture and mining activities, the higher emission values. The expected sign of the variable LnT could be negative or positive since the impact of trade on emissions depends on the development grade of the countries. The expected sign of the variable LnPPP and LnY could be positive or negative. As mentioned before, the ECI increases in the host economy, research and development activities and skills will be improved and clean technologies and environmentally friendly production might be started so, the expected sign of the variable ECI is negative.

The slope homogeneity and cross-sectional independency have been tested in the panel. For testing slope homogeneity, the statistics Δ and Δ_{adj} proposed by Pesaran and Yamagata [66] have been calculated. If a random shock occurring in any of the units in the panel data set affects the other units, the problem of CSD arises among the units in the panel so, the first-generation unit root tests might be given suspicious and misleading results [65,67]. In the current study, LM test by Breusch and Pagan [68], CD test by Pesaran [69] and scaled LM test by Pesaran et al. [70] are implemented to test CSD. Their test statistics for the null $H_0 : Cov(\varepsilon_{it}, \varepsilon_{jt}) = 0, i \neq j$ are given in Eqs. (2)–(4).

$$LM = T \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{ij}^2 \tag{2}$$

$$CD = \sqrt{\frac{2T}{N(N-1)}} \left(\sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{ij} \right) \tag{3}$$

$$scaledLM = \sqrt{\left(\frac{2}{N(N-1)}\right)} \sum_{i=1}^{N-1} \sum\nolimits_{j=i+1}^{N} \frac{(T-k)\hat{\rho}_{ij}^2 - \mu_{Tij}}{\upsilon_{Tij}^2} \tag{4}$$

In Eqs. (2)–(4), $\hat{\rho}_{ij}$ stands for estimated correlation between units i and j. N and T are number of units and length of time dimension of the panel data set. In Eq. (4), μ and υ are mean and the variance of $\hat{\rho}_{ij}^2$ respectively. LM statistic is χ^2 distributed asymptotically and the others are standard normally distributed.

Under the CSD, we used the cross-sectional augmented ADF (CADF) and the cross-sectional augmented IPS (CIPS) tests by Pesaran [71]. CADF test equation is given in Eq. (5).

$$\Delta y_{it} = \alpha_{it} + \beta_i y_{it-1} + \rho_i t + \sum_{j=1}^{p} \theta_{ij} \Delta y_{i,t-j} + \epsilon_{it} \tag{5}$$

In Eq. (5), y_{it} stands for the series analysed, t stands for trend term and here the lag value p can be determined by using BIC statistic. CIPS test statistic is given in Eq. (6).

$$CIPS(N,T) = N^{-1} \sum_{i=1}^{N} t_i(N,T) \tag{6}$$

In Eq. (6), test statistics t_i are obtained from the CADF equation given in Eq. (5). For both CADF and CIPS tests, the null is that all individuals are nonstationary and the alternative is that at least one of them is stationary.

Westerlund co-integration test by Westerlund [61] was performed. This test is robust co-integration test under the cross-sectional dependency. Westerlund co-integration strategy gives two test statistics (sz_t and sz_rho) called as group statistics for testing co-integration relationship of all panel and other two test statistics (pz_t and pz_rho) called as (panel statistics) for testing co-integration relationship of at least one cross-sectional unit. The null of Westerlund co-integration test is that there is no error correction, so in the case of the rejecting the null, series will be cointegrated.

To estimate long-run equation under the CSD, we used CUP-FM and CUP-BC estimators by Bai et al. [72]. The econometric tests are powerful in the panel data set having CSD and also these approaches can control unobserved nonlinearity, serial correlation and endogeneity and asymptotic bias.

Finally, we run causality method by Dumitrescu and Hurlin [62] to get short-run causality. The causality test accounts the CSD and unobserved heterogeneity in the panel data.

Empirical results and discussion

This study starts the empirical analysis by investigating the slope heterogeneity in the panel and evidences are displayed in Table 1. The result indicates the presence of slope heterogeneity in the data by rejecting the null hypothesis (slope homogeneity) at 1% significance level. The next step is to check CSD in the panel and results are indicated in Table 2. In this modern world, countries have connections with each other, have trade agreements with each other's and sharing boarder with each other. These counties create economic dependence of countries with each other. So, this thing forces us to examine the CSD in the data. As we can notice that all variables are statistically significant at 1% significance level, it indicates the presence of CSD in the data. Therefore, we reject the null hypothesis and accept the alternative hypothesis. The results of slope homogeneity and CSD tests indicate that the panel analyzed is heterogeneous and cross-sectionally dependent and also these results prove the accuracy of the econometric methods used in the current study.

In the next step, we explore the stationary properties of variables in the presence of CSD. For this purpose, this paper uses CIPS and CADF methods and results are represented in Table 3. All variables contain unit roots (non-stationary) and the variables become stationary (no unit root) after taking the 1st differences.

After examining the stationary properties of each variable of study, the next is investigating the long run equilibrium association between CO_2 emissions, economic complexity, trade openness, public–private partnership in energy sector and natural resources. Since, CD methods show the presence of CSD among the variables, so the results drive from first-generation cointegration methods (e.g., Pedroni, Kao, and Fisher and Johansen) may provide spurious results. This study uses Westerlund [61] cointegration methods which overcome the issue of CSD. Table 4 indicates the group and panel statistics of cointegration among the variables. As we can notice that each statistic is significant at 1% significance level and this indicates the presence of a long-run relationship among carbon emissions, economic complexity, public-private partnership in energy sector, natural resources, and trade openness.

After determining the cointegration, now this study will calculate the coefficient of each independent variable with respect to dependent variable. The results of Cup-FM and Cup-BC are presented in Table 4. Both methods show almost similar results in the sense of coefficient magnitude and significance level.

The coefficient sign of natural resources is positive and significant with respect to CO_2 emissions. In this context, a 1% increase in natural resources increases CO_2 emissions by 0.166 (0.164)%. It implies that natural resources cause to increase the level of emissions. The results coincide with the results of Khan et al. [24] and Muhammad et al. [73] and contradict the Danish et al. [27] study. The possible reason is that these countries use outdated technology to extract the resources which pollute the environmental quality. Moreover, these economies may use polluted natural resources (e.g. coal and oil) to achieve the higher economic growth in the country which cause to increase emissions level.

The results suggest negative and significant link between trade openness and CO_2 emissions. A 1% increase in trade openness causes a reduce emissions level by −0.271 (−0.257)% in BRICS countries. It implies that trade openness is important factor to control the level of emissions in these nations. These results follow the results of Wang et al. [35], but the findings of this study do not match those of Danish and Wang [22]. The possible reason of this negative sign is that these countries are using modernize technology for trade (import–export). More specifically, these countries import latest technology from rest of the world for manufacturing the goods and then install these technologies to production the goods all large scale for export.

Table 4 shows positive and significant link between PPP and CO_2 emissions level in the environment. A 1% increase in PPP causes an increase in emissions intensity by 0.005 (0.014)%. Estimated PPP coefficients are very low as compare to the coefficients of natural resources and income. It implies that PPP produces low emissions as compare to the natural resources and income. Empirical findings show that PPP has not yet reached the level to improve environmental quality. Governments should accelerate the transition from fossil-based technologies to clean energy for environmental sustainability, taking into account economic policies. Because it is seen that PPP investments are not enough to increase environmental quality without serious transformation in energy. This finding ensures support for prior papers such as Shahbaz et al. [9], Khan et al. [74], Chen et al. [56] for China.

The impact of ECI on emissions is negative and significant. A 1% improve in ECI cause to reduce emissions by −0.0557 (−0.065)%. The empirical arguments on the impacts of economic complexity on emissions is similar to the previous findings for 55 Countries [51]. Though, economic complexity reduces very little emissions from the environment as compare to the trade openness. These countries bring environmental awareness in different sectors (agriculture, firms, industries) of the economic development.

The positive impact found of economic growth on CO_2 emissions for BRICS economies. As we can notice that income is highly contributor of emissions in the environment as compare of the independent variables. These group of countries are using non-renewable energy for higher

Table 1
Slope Homogeneity test.

Statistic	*P*-value
$\tilde{\Delta} = 9.698^{***}$	0.000
$\tilde{\Delta}_{adj} = 11.135^{***}$	0.000

*** significant at 1% level.

Table 2
CSD tests results.

Variables	*Breusch-Pagan LM*	*Pesaran scaled LM*	*Pesaran CD*
$LnCO_2$	248.694***	53.373***	15.706***
LnY	258.594***	55.587***	16.062***
LnNR	119.881***	24.570***	10.591***
LnT	105.944***	21.453***	8.075***
LnPP	37.784***	6.212***	2.764***
ECI	88.445***	17.540***	4.938***

*** significant at 1% level.

Table 3
CIPS and CADF tests results.

Variables	*CIPS*		*CADF*	
	Level	*First-Difference*	*Level*	*First-Difference*
$LnCO_2$	−2.353	−5.808***	−1.919	−4.131***
LnY	−2.144	−3.676***	−2.436	−3.110***
LnNR	−2.662	−5.366***	−2.347	−3.797***
LnT	−2.676	−4.475***	−2.566	−4.296***
LnPP	−2.785	−5.450***	−2.803	−3.716***
ECI	−2.516	−5.668***	−2.520	−3.287***

*** significant at 1% level.

Table 4
Westerlund [61] cointegration test results.

	Constant		*Trent*	
test	*Statistic*	*P-value*	*Statistic*	*P-value*
sz_t	4.5537***	0.000	5.4551***	0.000
sz_rho	5.7838***	0.000	6.3134***	0.000
pz_t	5.2981 ***	0.000	6.3160***	0.000
pz_rho	5.0204 ***	0.000	5.0546***	0.000

*** significant at 1% level.

income growth which results in produce higher carbon emissions.

Table 5 shows the results of DH causality methods. The results indicate a unidirectional causality from natural resources, trade openness, and income to CO_2 emissions. It implies that if any change occurs in natural resources, trade openness, and income it directly causes a change in carbon emissions. A bidirectional causal relationship found between ECI and CO_2 emissions at 1 and 10% significance levels. ECI effects CO_2 emissions, and in return CO_2 emissions also affect ECI. The DH causality results indicate that natural resources Granger cause trade openness and income at 10% significance level. A unidirectional link exists, which is coming from a PPP to trade openness. It implies that public–private partnerships investment in energy effect trade openness. A similar relationship exists which is coming from ECI to PPP Table 6.

Conclusion and policy recommendation

This paper scrutinizes the relationship between natural resources, economic growth, public–private partnership, trade openness, and CO_2 emissions. To achieve this goal, it uses robust econometric approaches that take into account CSD and slope heterogeneity. The econometric results show that the approaches testing the cross-section dependency and the slope heterogenicity test confirm the correlation between cross-section units and slope heterogeneity across economies. In fact, it is the expected result that countries will be affected by each other's possible movements in the globalizing world. Because countries are bound by certain agreements (i.e., trade or environmental), and especially in economies in the same group (i.e., BRICS, European Union, G7 and MENA), the decision made by one can affect the others. Thus, second generation panel unit root and cointegration approaches should be used to advance in analysis. The CIPS and CADF unit root test results indicate that variables are first-order stationary, which allows the application of the Westerlund [61] approach in this study. The Westerlund [61] approach confirms the long-term relationship among public–private cooperation, natural resources, trade openness economic growth, and CO_2 emissions.

After finding a long-run cointegration link between CO_2 emissions and independent variables, long-term coefficients are obtained with Cup-FM and Cup-BC estimators. The results of both estimators are very close and consistent. In the long run, economic complexity and trade openness stimulate environmental quality in BRICS economies. On the contrary, natural resources, economic growth and public–private partnership contribute to the increase of environmental degradation in BRICS economies. Finally, the DH test shows important results for the interrelationships between variables.

This study presents important policy implications. As natural resources increase carbon emissions, it signifies that natural resources reduce environmental quality in BRICS countries. The policy maker develops such policies which reduce the consumption of polluted natural resources and increase the consumption of clean natural resources. Technology can play an important role in the process of natural resources depletion. The quantity of carbon emissions can be reduced by extract the natural resources with latest technology.

A positive link exists between public–private partnerships investment in energy and CO_2 emissions. These countries could not achieve environmental sustainability if they continue to invest in dirty energy via public–private partnerships. The policymakers of these countries should develop policies which boost the investment in renewable energy project via public–private partnerships and discourage the investment in dirty energy (e.g., oil, gas, and coal). In BRICS economies, governments should ensure that the private sector focuses on clean energy with long-term returns, rather than focusing on short-term goals. Investment in the renewable energy sector can increase if the government offers more financial incentives to the private sector in this partnership. Thus, public–private cooperation can contribute to environmental sustainability.

Another important result of the study is the existence of a positive relationship between trade and environmental quality. It is seen that BRICS economies make clean production with technological investments in the production of export goods. This result complements the Danish and Ulucak [75], which investigates the impacts of environmental technologies on emissions in BRICS countries. They have shown that with the development of environmental technologies, emissions will decrease. BRICS countries should not lose this feature with the increasing globalization. On the contrary, production should continue with more green technology. Especially the countries can contribute to environmental sustainability by making agreements with the slogan of green export. Steiner [76] states that innovative financial mechanisms such as the New Development Bank and the Conditional Reserve Arrangement under BRICS are sufficient to create a permanent green infrastructure and longer-term competitiveness for the countries. With the more effective use of these financial institutions belonging to the economies, trade can continue to contribute to environmental development.

Finally, the negative link between economic complexity and environmental pollution implies that a certain level of expertise has been achieved in the production of goods in BRICS economies. Thus, it is inevitable that the goods produced by experts and talented employees are environmentally friendly. In addition, as the capabilities reach a certain level, the amount of emissions from the production of each good is expected to decrease. Moreover, due to the sophistication of complex goods, economic returns can be high and these productions contribute to economic efficiency. BRICS countries need to take some steps to maintain and improve this production quality. For example, governments should provide tax benefits and research and development grants to firms that produce sophisticated goods. In addition, investments should be made to establish educational workshops in order to further increase the skills of employees in these companies.

Finally, economic growth appears to be the most important cause of environmental degradation in our study. This result indicates that intense fossil energy consumption is still common in the economies and the share of renewable energy technologies is not at a level to increase environmental quality. BRICS economies aiming at economic growth should also take environmental quality into account. Intensive production and consumption activities are taking place in these countries. However, there is not enough ground for green production yet. To achieve this, BRICS countries must implement strict environmental policies, along with sustainable growth, and extend expertise in the production of complex goods to other production activities.

Table 5
Results of Cup-FM and Cup-BC tests.

Variables	*Cup-FM*		*Cup-BC*	
	Coefficient	t-statistics	Coefficient	t-statistics
LnNR	0.1665***	5.9967	0.1644***	7.5120
LnT	−0.2713***	−5.9546	−0.2570***	−7.5182
LnPP	0.0055**	2.2150	0.0147**	2.20535
ECI	−0.0557***	3.2960	−0.0657***	−4.8295
LnY	0.6795***	12.833	0.6399***	13.7812

*** significant at 1% level.
** significant at 5% level.

CRediT authorship contribution statement

Abdullah Emre Caglar: Project administration, Supervision, Writing – review & editing, Writing – original draft. **Muhammad Wasif Zafar:** Conceptualization, Methodology, Software, Writing – original draft. **Festus Victor Bekun:** Writing – original draft, Validation. **Mehmet Mert:** Methodology, Writing – review & editing.

Table 6
DH Panel causality results.

	$LnCO_2$	LnNR	LnT	LnPP	EC	LnY
$LnCO_2$	———	2.763***	1.613*	0.207	1.730*	2.137**
LnNR	−0.117	———	1.329	−0.614	0.102	−0.405
LnT	0.036	−0.160*	———	2.511**	−0.623	−0.245
LnPP	0.356	0.314	0.551	———	−1.928**	0.468
EC	3.342***	−0.865	−0.793	−0.587	——	−0.036
LnY	−0.565	1.688*	1.096	−0.281	−1.374	———

*** significant value at 1%
** significant value at 5%
* significant value at 10%

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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