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# FDI, Green Innovation and Environmental Quality Nexus: New Insights from BRICS Economies

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**Abstract:** One major concern about foreign direct investment (FDI) is the potential negative environmental impact due to increased $CO_2$ emissions. However, there is a possibility that FDI mitigates $CO_2$ emissions through green innovation and creates a cleaner environment. In the existing literature, there is no significant empirical evidence on the linkage among FDI, green innovation and $CO_2$ emissions in the context of BRICS countries. Hence, this study aims to analyze the impact of FDI and green innovation on the environmental quality of BRICS economies for 1990–2014. The study employed Augmented Mean Group (AMG) estimators for empirical data analysis. The study's findings depict that foreign direct investment, energy use, and economic growth have a significant and positive impact on the $CO_2$ emissions of BRICS economies. Moreover, green innovation has a significant inverse impact on $CO_2$ emissions. The results show bidirectional causalities between $CO_2$ emissions and green innovation, trade openness and $CO_2$ emissions, energy use and $CO_2$ emissions, and urbanization and $CO_2$ emissions. Additionally, the findings reveal a one-way causality from $CO_2$ emissions to GDP and $CO_2$ emissions to urbanization. This study offers essential policy recommendations for the environmental sustainability of BRICS countries through green innovation.

**Keywords:** foreign direct investment; green innovation; $CO_2$ emissions; BRICS; environmental sustainability; clean technology

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## 1. Introduction

During the last few decades, foreign direct investment has contributed to producing highly advanced and high-tech products. FDI has a significant impact on the technology innovations of the host countries [1]. Researchers and policymakers have termed FDI as the primary economic growth tool and recognized it as an established source of employment and channel of technology transfer to its host economies [2–7]. On the other hand, the negative perspective regarding foreign direct investment is the potentially harmful environmental effects of FDI [8,9]. FDI enhances the production processes in the host countries, and can be detrimental to the environment. The production activities result in the economic benefits of the host economies, but the environmental cost can sometimes be higher than the financial gains Therefore, many countries have realized the ecological cost of production processes nowadays, mainly foreign direct investment in the host countries. Therefore, the majority of governments are concerned about the consequences of FDI and production activities. To resolve the issues related to the deteriorating effects of FDI, various governments are welcoming green innovation in their countries. Green innovation can minimize the adverse effects of industrial production processes [10].

Green innovation can mitigate $CO_2$ emissions and provide a clean environment in the host economies. It has been seen that the production technologies used by foreign firms are comparatively more protective than the domestic technologies in developing countries [11] Due to the significant capability of green innovation to deal with environmental challenges, developing countries search for green technology innovation and environmentally friendly production processes. FDI improves the quality of the environment in the host economies through clean technology [12]. In addition, foreign direct investment enhances the host countries' capital sources and production capacity. It is also a vital source of technology transfer to the host countries [13,14]. Advanced management practices enter the host countries and enhance productivity [15]. It is often observed that multinational companies follow comparatively cleaner and environmentally friendly management practices than domestic enterprises. In short, foreign companies are more responsible in dealing with environmental challenges [11]. The multinational corporations entering into developing countries where environmental standards are lower usually carry quality production technologies that are more environmentally friendly and advanced than those present in the host countries' enterprises [16].

FDI and other economic growth variables, such as trade openness, urbanization, and energy use, consume high amounts of fossil fuels. Consumption of fossil fuels increases $CO_2$ emissions and pollutes the whole environment [17,18]. Foreign direct investment and trade increase energy use and global manufacturing. The global manufacturing expansion severely affects the global climate [19,20]. Although foreign direct investment and trade openness boost $CO_2$ emissions, they can also mitigate the negative impacts of $CO_2$ emissions through renewable energy sources [21,22].

Due to the vulnerable ecosystem, developing nations are more concerned about environmental sustainability. Therefore, environmental sustainability has become a significant policy concern for the world. Environmental sustainability is referred to as obstinate ecology protection by ensuring ecological resources' safety [23]. Recently, environmental sustainability has been raised as a hot debate globally. The countries are receiving significant pressure domestically and internationally regarding environmental protection [21]. The Paris agreement on ecological sustainability is one of the major steps towards biodiversity conservation. The negative impact of non-renewable energy on the natural environment has met the attention of all stakeholders. Therefore, the demands for alternative or renewable energies increased in recent years. In addition, renewable energy transition is declared as one of the vital parts of the Sustainable Development Goals (SDG) [24]. Renewable energy transition has key benefits; for example, it can help fight future global energy crises and environmental protection. FDI is the best source of technological diffusion as well as capital accumulation. Various studies have proven that FDI spoils the natural environment in the host country. However, FDI in renewable energy, such as renewable electricity production, can reduce environmental damage [25]. The United Nations' 2030 agenda of SDGs also promotes FDI in renewable energies.

BRICS (Brazil, Russia, India, China, and South Africa) countries have placed themselves globally in the most growing economies. They make a considerable contribution to world economic development [26]. The share of BRICS in the world GDP was estimated at 23.3 in 2007, i.e., USD 18.82 trillion. BRICS countries significantly impact the whole economy of the world as, jointly, 41 percent of the world population is made by BRICS alone. Additionally, BRICS countries cover more than a quarter of the area of the world [27]. Due to the enormous significance of BRICS economies, many FDI inflows enter into the BRICS countries. Moreover, there has been a significant increase in FDI inflows of BRICS countries. Between 2000 and 2018, the global FDI share increased to 19 percent from 6 percent [28]. On the other hand, the fast economic development in the BRICS countries has affected environmental sustainability. According to estimation, 13.985 billion tons of $CO_2$ emissions have been produced across BRICS countries. More specifically, BRICS made 41% of the total $CO_2$ emissions of the world [29]. Due to the growing importance of BRICS for the world economy, we have investigated the nexus among FDI, green innovation, and the environment for 1990–2014. To the best of our knowledge, there is no significant study investigating the nexus among FDI, green innovation, and environmental quality. The remaining part of this paper includes a literature review, methodology, discussion and results, conclusion, and policy recommendations.

## 2. Literature Review

Numerous studies have investigated the association between FDI and environmental quality nexus and offered mixed results; however, to the best of our knowledge, no significant studies examine the FDI, green innovation, and environmental quality nexus, particularly in BRICS countries. Therefore, this study mainly investigates the FDI, green innovations, and environmental quality nexus in BRICS economies.

### *2.1. FDI and Environmental Quality*

In our study, we have used $CO_2$ emissions to assess environmental quality. Good environmental quality is linked with lower $CO_2$ emissions, while poor environmental quality is associated with higher $CO_2$ emissions. There are two significant concepts on the relationship between FDI and the natural environment. Some studies conclude that FDI damages the natural environment under the pollution heaven hypothesis; however, others show that FDI improves environmental quality through diffusion and transfer of green technologies. Many studies have attested that FDI reduces pollution through green innovation [11,15,30,31]. A study conducted by Eskeland and E [32] revealed that United States' production units operating in developing economies follow environmentally friendly management practices, and clean energy is utilized in their industrial processes. A study on Gulf Cooperation Council countries analyzed the impressions of FDI inflows on the environment. The study employed a multivariate framework, and the results show a positive impact of FDI on the environment [33] The authors of Demena and Afesorgbor [34] investigated FDI and the environment nexus through the meta-analysis of 65 primary studies that generate 1006 elasticities. Their results illustrate that the impacts of FDI on $CO_2$ emissions are near zero. However, the heterogeneity of the studies shows that FDI considerably decreases $CO_2$ emissions. The findings were robust after disaggregation of the effects for different countries at different development levels and pollutant levels. The performance of carbon emissions in 71 countries for 1992–2012 was examined by Du and Li [35]. They employed a parametric Malmquist index methodology. The study results found a rise in total-factor carbon productivity in all countries during the study period. Moreover, technology innovation is the critical factor for improving total-factor carbon productivity. The spillover effects of China's OFDI on the green innovations of 30 provinces for 2006–2015 were examined by Zhou et al. [36] The study found that Chinese OFDI does not result in green innovations, but there were significant heterogeneities across different provinces due to the absence of prerequisite supportive conditions. The FDI and emissions nexus was analyzed by Udemba et al. [37] by employing Pesaran's autoregressive distributed lag-bound test; the authors found that FDI damages the environmental quality. FDI was also found to degrade the environment by Solarin et al. [38].

### *2.2. Green Innovation and Environmental Quality*

In the last two decades, green innovation has received tremendous attention due to its ability to deal with environmental issues. Green innovation is defined as the novelty in production and process, which can reduce the environmental impact [39,40]. Green innovation lowers environmental costs and introduces environmentally friendly technologies. It guarantees environmental security by lowering environmental damages [41]. The nexus among green innovation and $CO_2$ emissions was studied by Wein et al. [42] in 95 provinces of Italy for 1990–2010. The study found that green innovation improves environmental productivity, but it does not significantly reduce $CO_2$ emissions. The impact of innovations on the environment was investigated by Carrión-Flores and Innes [43] who found bidirectional causalities between innovation and air pollution in 127 manufacturing units for 1989–2004. The study used patent count as a proxy of innovation. Another study analyzed the connection between patents and $CO_2$ emissions in different provinces of China. The study's findings depict that fossil fuel-based patent technologies do not significantly reduce carbon emissions. However, carbon-free patents or green patents substantially reduce carbon emissions in East China [44]. The impact of innovation on climate change using different empirical techniques in 70 economies was examined by Su and Moaniba [45]. The study employed patent count as a proxy of innovations and $CO_2$ as a proxy of climate change. The study found that innovations reduce $CO_2$ emissions. A long-run relationship between energy intensity and green energy innovation in two OECD countries for 1975–2014 was determined by Kanto and Mazzanti [46] The study found a long-run and short-run relationship between energy innovation and energy intensity. The connection among GDP per capita, R&D, renewable and non-renewable energy, and $CO_2$ emissions in 28 OECD member countries was studied by Mensah et al. [47]. The study indicates that per capita GDP and non-renewable energy raise carbon emissions, and research and development expenditure decreases emissions. The study suggests that innovation can improve environmental quality across OECD countries. Another study also demonstrated that R&D expenditure reduces $CO_2$ emissions in European firms [48]. Along the same lines, Ma et al. [49] found that investment in R&D, technology innovation and renewable energy usage reduces the $CO_2$ emissions in the case of China. The validity of the EKC hypothesis in the case of G7 economies was endorsed by Qin et al. [50]. The study results depict that research and development in renewable energy decrease carbon emissions. The nexus between $CO_2$ emissions and green innovation was examined by Yuan et al. [51] by using institutional quality as a moderating variable. The authors found that green innovation significantly reduces $CO_2$ emissions. Foreign investments and green innovation were confirmed by Demena and Afesorgbor [34] to improve the environmental quality by lowering carbon emissions.

### *2.3. Trade Openness and Environmental Quality*

Several studies found that trade openness deteriorates the quality of the environment by increasing $CO_2$ emissions. [52–54]. In the same vein, Jun et al. [55] examined the relationship between trade openness and environmental quality in the case of China. According to their results, trade openness reduces environmental quality, and the pollution heaven hypothesis is verified in the case of China. Nonetheless, other studies, including Managi et al. [56] and Saud et al. [57], believe that trade openness declines $CO_2$ emissions. However, the effects of trade openness on the environment were revealed by Le et al. [58] to vary from region to region; trade openness positively impacts the environmental quality of developed and high-income countries, while it negatively affects low-income countries. Trade openness and environment relationship were analyzed by Sharif Hossain [59] who found that trade openness positively impacts the environmental quality. Various studies have thoroughly examined economic growth, urbanization, energy use, and the environment nexus. For example, the impact of economic growth and urbanization on the emissions in 147 economies was analyzed by Liobikienė and Butkus [60]. The results depict that economic growth and urbanization both decrease emissions with the help of efficient energy utilization. Therefore, green innovation should be adopted to ensure the sustainability of the environment [61]. The main factors affecting $CO_2$ emissions include economic growth, energy use, and urbanization in various developed and developing economies.

### *2.4. Urbanization and Environmental Quality*

The growing global population and migration have increased urbanization. Due to increased urbanization, energy use has increased in urban areas, especially in transportation and industrial environments. The relationship between urbanization and environmental sustainability has been extensively investigated in the available literature; however, the results are mixed. An empirical study on Southeast Asian countries conducted by Wang et al. [62] showed that urbanization results in $CO_2$ emissions. The study of Azam and Khan [63] reveals that urbanization damages the natural environment in India and Bangladesh while urbanization improves the environment in Sri Lanka. Moreover, a similar relationship was found in the case of Pakistan. A positive association between urbanization and $CO_2$ emissions was also found by Shahbaz et al. [64] in the case of the UAE. In addition, analyzed the relationship between urbanization and emissions of BRICS countries was analyzed by Zhu et al. [65] and found that urbanization declines $CO_2$ emissions. In contrast, the study of Ali et al. [66] concludes that economic growth spoils the environment; however, urbanization does not harm the natural environment in most urbanized countries, such as Singapore. The study of Bekhet and Othman [67] depicted that urbanization and $CO_2$ emissions have an inverted U-shaped connection. The EKC hypothesis analyzes the long-run relationship between economic growth and the environment. According to EKC, there was an inverted U-shaped relationship between environment and per capita income.

### *2.5. Economic Growth and Environmental Quality*

As per EKC theory, an increase in GDP results in pollution during the first economic development phase, but $CO_2$ emissions decrease with the rise in income [68]. Economic growth at its initial stage damages the environment for various reasons, such as abundant use of non-renewable energy, traditional production methods, and lack of awareness regarding environmental conservation. Moreover, at the initial stage of development, countries focus more on increasing GDP than caring for the natural environment. Various other studies also analyzed the EKC hypothesis; for instance, Omri et al. [69], Zoundi [70], and Saud et al. [57] also confirm the EKC hypothesis. However, the study by Lorente et al. [71] shows an N-shaped connection between GDP and emissions. Some other studies have been conducted on the EKC hypothesis and with results showing a non-existence of the EKC hypothesis for their selected countries of study Mikayilov et al.; Zambrano-Monserrate et al. [72,73]. Similarly, the studies of Richmond and Kaufmann [74] and Omisakin and Olusegun [75] also explore the relationship between GDP and environmental pollution. According to their findings, there is insignificant causality among dependent and main independent variables. Further, Wen et al. conclude that economic growth has a significant and positive impact on $CO_2$ emissions in the case of South Asian economies. According to the study of Zeraibi et al. [76], economic growth and financial development increase $CO_2$ ecological footprints in the case of five Southeast Asian countries, namely Indonesia, Malaysia, the Philippines, Thailand, and Vietnam. However, technological innovation and renewable electricity generation decrease ecological footprints.

### *2.6. Energy Consumption and Environmental Quality*

Various studies have investigated the relationship of energy usage with environmental sustainability. Some studies have separated energy usage into two main types: renewable and non-renewable energy. Non-renewable energy could be obtained from non-renewable natural resources, such as fossil fuels. Therefore, the consumption of non-renewable energy leads to an increase in $CO_2$ emissions. On the contrary, renewable energy is generated from renewable resources such as solar, wind, and biomass. Thus, renewable energy is considered environmentally friendly energy. Numerous studies have investigated both energy consumption and total energy consumption on the environment in the available literature. As per the findings of Qin et al. [50], consumption of non-renewable energy increases $CO_2$ emissions; however, the usage of renewable energy improves the environmental quality. Renewable energy consumption enhances the environmental quality in Mexico, but in the case of Morocco, renewable energy with interactions of financial development and FDI reduces the $CO_2$ emissions [24]. Moreover, the impact of FDI, renewable energy consumption, and energy innovations on environmental quality were analyzed by Balsalobre-Lorente et al. [25]. According to their findings, FDI spoils the environment under the pollution heaven hypothesis, and renewable energy consumption improves environmental quality. Moreover, energy innovation plays a moderating role in the relationship between FDI inflows and environmental quality.

## 3. Materials and Methods

### *3.1. Model Specification*

It is seen that $CO_2$ emissions are used to assess environmental quality. Good environmental quality is linked with lower $CO_2$ emissions, while poor environmental quality is associated with higher $CO_2$ emissions [77–79]. Similarly, green innovation is measured in environmental technology patents, and it is observed as a positive and significant element of environmental quality [9,39]. Moreover, FDI, trade openness, GDP, and urbanization are the significant determinants of $CO_2$ emissions [77,80]. The existing literature indicates that all the variables mentioned above affect the environmental quality of various regions. Therefore, it is inevitable that FDI, green innovation, trade openness, GDP, and urbanization have a significant impact on the environmental quality of BRICS. Based on these arguments, we have defined our model as mentioned below.

$$CO_2 = f(FDI_{it},\ TO_{it}, GDP_{it,} URB_{it},\ EU_{it}, GI_{it}) \tag{1}$$

All the variables have been transformed into logarithm form as specified in the below equation.

$$lnCO_{2it} = \alpha_0 + \beta_1 FDI_{it} + \beta_2 TO_{it} + \beta_3 GDP_{it} + \beta_4 URB_{it} + \beta_5 EU_{it} + \beta_6 GI_{it} + \mu_{it} \tag{2}$$

In the above equation, $t$ shows time (1990–2014), and $i$ indicates BRICS countries, $\alpha_0$ stands for the constant term while $\mu_{it}$ is used for the error term. Moreover, $\beta_1$, $\beta_2$, $\beta_3$, $\beta_4$, $\beta_5$, and $\beta_6$ represent undermined coefficients.

### *3.2. Data and Variables*

We collected data of five BRICS countries (Brazil, Russia, India, China, and South Africa) for 1990–2014. The data period is based on data availability, as the latest data of the dependent variable of the study $CO_2$ emissions are available until 2014. The variable $CO_2$ emissions is the proxy of environmental quality, and it is quantified in metric tons per capita, as with other studies [38,47,72]. We assumed that lower $CO_2$ emissions depict better environmental quality, and higher $CO_2$ emissions indicate poor environmental quality. We obtained data on $CO_2$ emissions from World Bank Development Indicators.

The study's independent variables include FDI, green innovation, trade openness, urbanization, and energy use. By following Wen et al. [39], we measured green innovation by environmental technology patents. It refers to patenting of environmentally friendly or green technology. Green innovation refers to environmentally friendly technology that lessens environmental degradation. The data of green innovation (GI) were obtained from the (OECD) Organization for Economic Cooperation and Development database. Other independent variables, such as FDI, show foreign direct investment net inflows (% of GDP) while GDP per capita is a proxy of economic growth. Energy use is measured in kg of oil equivalent per capita. Urbanization is the population density ratio, and it is estimated in people per square km of land. We obtained data for all these variables from the World Bank database. Trade openness is measured by the total sum of imports and exports; the data were obtained from the UNTCAD (United Nations Conference on Trade and Development) database. Table 1 provides a detailed picture of variables and their definitions, measurement units, and data sources.

**Table 1.** Variablesand measurement units.

| Variable | Symbols | Measurement Units | Source |
| --- | --- | --- | --- |
| Green Innovation | GI | Total number of green patents | OECD (2020) |
| $CO_2$ emissions | $CO_2$ | Metric tons per capita | WDI (2020) |
| Foreign direct investment | FDI | "Foreign direct investment, net inflows (% of GDP)" | √ |
| Total energy use | EU | kg of oil equivalent per capita | √ |
| GDP per capita | GDP | GDP per capita (constant 2010 US$) | √ |
| Urbanization | UR | Population per square km of land | √ |
| Trade openness | TO | "Total trade of goods and services measured in millions of constant US dollars" | UNTCAD (2020) |

Scheme 2020. Note: WDI is World Development Indicators and UNTCAD is United Nations Conference on Trade and Development.

### 3.3. Descriptive Statistics

We collected data from WDI, OECD, and UNTCAD databases for all five BRICS countries for 1990–2014. The study period was chosen based on data availability. Table 2 provides the descriptive statistics. We found that the maximum value for the green innovation was recorded at 801,135, while the minimum value was 138. The mean value for green innovation was 37,647.39. The minimum and maximum values for $CO_2$ emissions were recorded at 0.7090008 and 24.39835, respectively, while 5.669826 was the mean value. The mean value for FDI was 2.084999with the −0.0655308 and 6.186882 minimum and maximum values, respectively. Energy use had a 350.0757 minimum value and 5941.586 maximum value, while 2031.53 was the mean value. −0.466841 and 4.601685 were the minimum and maximum values for urbanization, respectively. The mean value for urbanization was recorded at 2.168095. The GDP had a −14.61392 minimum value and 13.63582 maximum value with a 3.311594 mean value. Finally, trade openness had a minimum value of 22,911.06 and a maximum value of 2,462,902, while the mean value was 283,702.6.

**Table 2.** Descriptive statistics.

| Variable | | Mean | Std. Dev. | Min | Max | Observations |
| --- | --- | --- | --- | --- | --- | --- |
| GI | overall | 37,647.39 | 116,167.8 | 138 | 801,135 | N = 125 |
| | between | | 66,196.06 | 795.56 | 154830 | n = 5 |
| | within | | 99805.59 | −111350.6 | 683,952.4 | T = 25 |
| $CO_2$ | overall | 5.669826 | 4.70682 | 0.7090008 | 24.39835 | N = 125 |
| | between | | 4.839137 | 1.085205 | 12.47101 | n = 5 |
| | within | | 1.808114 | 3.326105 | 17.59716 | T = 25 |
| FDI | overall | 2.084999 | 1.558014 | −0.0655308 | 6.186882 | N = 125 |
| | between | | 1.049067 | 1.103614 | 3.712307 | n = 5 |
| | within | | 1.240916 | −0.6609998 | 6.76718 | T = 25 |
| EU | overall | 2031.53 | 1544.713 | 350.0757 | 5941.586 | N = 125 |
| | between | | 1676.868 | 453.5817 | 4699.7 | n = 5 |
| | within | | 344.2228 | 1313.33 | 3273.417 | T = 25 |
| UR | overall | 2.168095 | 1.346065 | −0.466841 | 4.601685 | N = 125 |
| | between | | 1.421947 | −0.0770906 | 3.782943 | n = 5 |
| | within | | 0.4257928 | 1.214635 | 3.11549 | T = 25 |
| GDP | overall | 3.311594 | 4.874774 | −14.61392 | 13.63582 | N = 125 |
| | between | | 3.501887 | 0.8178455 | 8.99968 | n = 5 |
| | within | | 3.724745 | −12.19254 | 12.88509 | T = 25 |
| TO | overall | 283,702.6 | 474,175.3 | 22,911.06 | 2,462,902 | N = 125 |
| | between | | 308,766.3 | 60,209.04 | 822,546.4 | n = 5 |
| | within | | 384,652.9 | −481,469.8 | 1,924,058 | T = 25 |

Note: Std. Dev. indicates standard deviation; Max and Min show maximum and minimum values, respectively.

### 3.4. Estimation Techniques

This study presents a systematic procedure to investigate Equation (2) empirically: (i) Pesaran CD (PCD) was used to examine cross-sectional dependence among the variables; (ii) Pesaran CADF and Pesaran CIPS panel unit root tests were used for the unit root tests; (iii) for observing cointegration among the variables, Westerlund cointegration, Pedroni-cointegration, and Kao-cointegration tests were employed; (iv) the AMG estimator was used for the long-run estimations andthe CCEMG estimator was used for robustness analysis; (v) to examine the directions of causalities, we employed Dumitrescu and Hurlin panel causality test.

#### 3.4.1. Cross-Sectional Dependence Tests

The cross-sectional dependence test is a prerequisite to avoid erroneous and biased results (Dong et al., 2017). Therefore, we employed the Pesaran cross-sectional dependence (PCD) test to check the data (Pesaran, 2004). The study's null hypothesis depicts that the cross-sections are independent, while the alternate shows that the cross-sections are dependent. The equation is mathematically written as follows:

$$CD = \sqrt{\frac{2}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} T_{ij} \partial_{ij} \rightarrow N\,(0,\,1) \tag{3}$$

where $\hat{\partial}^2{}_{ij}$ indicates coefficients of correlation that were obtained from the above model. Equation (3) is distributed asymptotically as standard normal when the null hypothesis is considered $N \rightarrow \infty$ and $T_{ij} \rightarrow \infty$.

#### 3.4.2. Panel Unit Root Tests

After confirming cross-sectional dependence in the panel, the unit root tests of the first generation, such as Im, Pesaran, and Shin (IPS), Augmented Dickey–Fuller (ADF), and Phillips–Perron (PP) seemed to be invalid. Hence, we choose second-generation unit root tests, i.e., Pesaran Augmented Dickey–Fuller (CADF) and the Pesaran cross-sectionally Augmented Im, Pesaran, and Shin (IPS) tests. Pesaran (2007) developed these tests. We can present the equation of CADF as follows:

$$X_{it} = a_i + b_i y_{i,t-1} + c_i \overline{y}_{t-1} + \sum_{j=0}^{k} d_{ik} \Delta \overline{y}_{t-j} + \sum_{j=1}^{k} d_{ik} \Delta y_{i,\,t-j} + \varepsilon_{it} \tag{4}$$

where $y_{i,t-1}$ and $\Delta y_{i,\,t-j}$ shows the first differences of each unit and the mean of lagged level cross-sectional values. After calculation of CADF, we can estimate the CIPS statistics as follows:

$$\text{CIPS} = N^{-1} \sum_{i=1}^{N} t_i(N, T) \tag{5}$$

where $t_i(N, T)$ shows t-statistics in the CADF test define in Equation (5).

#### 3.4.3. Panel Cointegration Tests

In the next step, we used cointegration tests after confirming cross-sectional dependence. Cointegration tests can be used to see if variables are related in the long run. The possibilities of a fractional long-term relationship are endless in the presence of cross-sectional dependence. To this purpose, we employed Pedroni [81], Kao [82], and Westerlund [83] cointegration tests based on the Durbin–Hausman principle. Westerlund cointegration test estimates cross-sectional dependence and employs a model with two autoregressive (AR) parameters unique to the panel: the panel-specific-AR and the same-AR test statistic. The null hypothesis rejection used by the panel-specific-AR tests statistics indicates the presence of cointegration. At the same time, the null hypothesis rejection of panel-specific-AR test statistics implies that there is no cointegration in the whole panel.

We can express panel-specific-AR test statistic as follows:

$$VR = \sum_{i=1}^{N} \sum_{t=1}^{T} \hat{E}^2{}_{ij} \hat{R}^{-1}{}_i \tag{6}$$

We can estimate same-AR test statistic as given below:

$$VR = \sum_{i=1}^{N} \sum_{t=1}^{T} \hat{E}^2{}_{ij} \left( \sum_{i=1}^{N} \hat{R}_i \right)^{-1} \tag{7}$$

where $VR$ indicates the group mean-variance-ratio statistics. $\hat{E}^2{}_{ij} = \sum_{t=1}^{T} \hat{e}_{ij}$, $\hat{R}_i = \sum_{t=1}^{T} \hat{e}^2{}_{ij}$, and $\hat{e}^2{}_{ij}$ represents the residuals of the panel regression model.

3.4.4. Panel Long-Run Parameter Estimates

We used the AMG estimator, which Eberhardt and Bond [84] introduced for calculating long-run parameters. Though the AMG technique is effective in cross-sectional relationships, its results seem outstanding for the panel data with heterogeneity [85]. Additionally, it has independence of the stationarity matter (Hussain et al., 2020). The Augmented Mean Group estimator permits cross-sectional dependence by integrating the common dynamic effect parameters, and we can estimate it through a two-steps technique as follows:

AMG-Step 1

$$\Delta y_{it} = a_i + b_i \Delta x_{it} + c_i f_t + \sum_{t=2}^{T} \delta_i \Delta D_t + \varepsilon_{it} \tag{8}$$

AMG-Step 2

$$\hat{b}_{AMG} = N^{-1} \sum_{i=1}^{N} \hat{b}_i \tag{9}$$

We employed the D–H panel causality test in our study. The D–H test was introduced by Dumitrescu and Hurlin [86]. We can write the equation for the D–H causality test as:

$$y_{it} = a_i + \sum_{j-1}^{K} \mu^j{}_i (y_{i(t-j)} + \sum_{j-1}^{K} \gamma^j{}_i (x_{i(t-j)} + \varepsilon_{it} \tag{10}$$

where $y$ and $x$ show observables; $\mu^j{}_i$ indicate the autoregressive parameters and $\gamma^j{}_i$ show the regression coefficients. There is no causal relationship in the panel according to the null hypothesis. The alternative hypothesis shows a causal connection in a minimum single cross-section unit. We can test our hypothesis based on an average Wald statistic as presented in the following equation:

$$W_{N.T}^{HNC} = N^{-1} \sum_{i=1}^{N} W_{i.T} \tag{11}$$

3.4.5. Robustness Analysis

For robustness analysis of AMG estimators, we have used CCEMG estimation techniques. Hussain et al. also used the same procedure for robustness analysis of AMG estimations.

3.4.6. Panel Causality Test

Long-run estimators investigate the impact of independent variables on the dependent variables, but they cannot determine the short-run causalities between the variables to formulate policies. Therefore, following [Hussain et el. [27] and Jun et al. [39], we used the Dumitrescu and Hurlintest to check the causalities in our panel. Dumitrescu and Hurlin (D–H) produce the most robust and consistent causal findings compared to other tests.

## 4. Results and Discussion

### *4.1. Findings of Cross-Sectional Dependence*

There is a cross-sectional dependence among the variables in the panel, as shown in Table 3. Our study rejected the null hypothesis at a 1% significance level, which justifies cross-sectional dependence in our study panel. We employed Pesaran (CADF) and Pesaran (CIPS) to check the stationarity of the variables, which is suitable in the presence of cross-sectional dependence [87].

**Table 3.** Cross-sectional dependence.

| Variable | P CD |
|---|---|
| GI | 12.789 *** |
| $CO_2$ | 14.982 *** |
| FDI | 12.146 *** |
| EU | 15.401 *** |
| UR | 7.439 *** |
| GDP | 7.986 *** |
| TO | 15.539 *** |

Note: P CD = Pesaran CD *** indicates significance at 1% level.

### *4.2. Outcomes of Panel Unit Root Test*

We used Pesaran (CADF) and Pesaran (CIPS) to check the stationarity of the variables. The outcome of both stationarity tests is presented in Table 4. We observed that the null hypothesis has been rejected at the level with intercept and trend. We found the stationarity at the 1% level for intercept and intercept and trend at first difference. The panel unit root test results show that the variables are integrated at first difference.

**Table 4.** Pesaran CADF and CIPS tests of unit roots.

| Variable | CADF | | | CIPS | |
|---|---|---|---|---|---|
| | Level | 1st-difference | | Level | 1st-difference |
| GI | −1.692 | −2.695 $^{\alpha}$ | | −1.619 | −4.765 $^{\alpha}$ |
| $CO_2$e | −3.116 $^{\alpha}$ | −3.387 $^{\alpha}$ | | −2.647 $^{\alpha}$ | −3.673 $^{\alpha}$ |
| FDI | −2.700 $^{\alpha}$ | −3.193 $^{\alpha}$ | | −2.782 $^{\alpha}$ | −4.841 $^{\alpha}$ |
| EU | −2.425 $^{\beta}$ | −2.528 $^{\beta}$ | | −1.306 | −2.636 $^{\alpha}$ |
| UR | −1.698 | −2.923 $^{\alpha}$ | | −0.943 | −3.162 $^{\alpha}$ |
| GDP | −2.426 $^{\beta}$ | −3.615 $^{\alpha}$ | | −3.524 $^{\alpha}$ | −5.182 $^{\alpha}$ |
| TO | −1.639 | −3.175 $^{\alpha}$ | | −1.402 | −2.869 $^{\alpha}$ |
| CIPSandCADFcritical values at | | | 10%<br>−2.21 | 5%<br>−2.33 | 1%<br>−2.57 |

Note: α and β indicate the significance level at 1% and 5%.

### *4.3. Findings of Panel Cointegration Test*

The Westerland, Pedroni, and Kao cointegration tests showed the existence of cointegration in the panel. The results of Westerland, Pedroni, and Kao cointegration tests show that the variables are cointegrated and significant, as shown in Table 5. The results of all cointegration tests are almost similar. Due to the existence of a cointegration relationship, we investigated the long-run estimations through AMG and CCEMG techniques.

**Table 5.** Panel co-integration test.

| | Statistic | $p$-Value(s) |
|---|---|---|
| Westerlund Cointegration | | |
| Some panels are cointegrated (VR)All panels are cointegrated (VR) | −1.3809<br>−1.7301 | 0.050<br>0.050 |
| Pedroni-cointegration | | |
| Modified Phillips–Perron t-statistics | 1.6236 | 0.0522 |
| Phillips–Perron t-statistics | −5.3252 | 0.0000 |
| Augmented Dickey–Fuller t-statistics | −2.7450 | 0.0000 |
| Kao-cointegration | | |
| Modified Dickey–Fuller (MDF) t-statistics | −8.5366 | 0.0000 |
| Dickey–Fuller(DF) t-statistics | −9.0297 | 0.0000 |
| Augmented Dickey–Fuller (ADF) t-statistics | −1.2890 | 0.0987 |
| Unadjusted modified Dickey–Fuller (UMDF) t-statistics | −12.0965 | 0.0000 |
| Unadjusted Dickey–Fuller(UDF) t-statistics | −9.4970 | 0.0000 |

### *4.4. Findings of Panel AMG Estimator*

This study investigates the impact of FDI, trade openness, GDP, urbanization, energy use, and green innovation on the environment of BRICS countries. AMG estimations show that FDI, EU, and GDP positively and significantly impact $CO_2$ emissions. The findings show that a unit increase in FDI will raise 0.0269% emissions in BRICS countries. These results are parallel with the results of Demena and Afesorgbor [34] and Hu et al. [9] According to the results, a unit increase in energy use will rise 0.786% in $CO_2$ emissions in the BRICS region. Similar results were also found by Khan et al. [17]. Additionally, a unit increase in the GDP leads to an increment of 0.00644% emissions in the BRICS panel. The study by [Wang et al.] also obtained the same results. Green innovation has a significant inverse relationship with $CO_2$ emissions. Results depict that there will be a decrease of 0.0956% emissions in BRICS countries in response to every unit increase of green innovation. These findings are related to the results of Kanto and Mazzanti [46].

### *4.5. Robustness Analysis*

To verify the robustness of the model, we investigated our data through CCEMG estimation techniques as shown in Table 6 The findings of CCEMG were found to be parallel with AMG estimation techniques. The results of AMG estimations depict that foreign direct investment, energy use, and economic growth have a positive and significant impact on $CO_2$ emissions. Green innovation has a significant inverse relationship with $CO_2$ emissions. Our findings of CCEMG are parallel with the results of Demena and Afesorgbor [34], Khan et al. [77] and Hu et al. [9].

### *4.6. Results of Dumitrescu–Hurlin Causality Test*

The Dumitrescu–Hurlin causality test was used to check the causality directions between the variable as shown in Table 7 We found bidirectional causalities between $CO_2$ emissions and green innovation, trade openness and $CO_2$ emissions, energy use and $CO_2$ emissions, and urbanization and $CO_2$ emissions. We detected a one-way causality from $CO_2$ emissions to GDP and $CO_2$ emissions to urbanization. Intisar et al. [88] and Le and Van [89] also employed the Dumitrescu–Hurlin causality test to find causalities among the variables.

**Table 6.** Results of panel AMG and CCEMG estimators.

| Variables | AMG($LnCO_2$) | CCEMG($LnCO_2$) |
|---|---|---|
| GI | −0.0956 *** (0.0343) | $-1.80\times 10^{-5}$ *** ($6.95 \times 10^{-6}$) |
| FDI | 0.0269 *** (0.00147) | 0.0154 *** (0.00581) |
| LnEU | 0.786 ** (0.358) | 1.158 *** (0.343) |
| UR | 0.00248 (0.0980) | 0.00130 (0.0162) |
| LnGDP | 0.00644 *** (0.000778) | 0.00174 ** (0.000745) |
| TO | $-4.06 \times 10^{-8}$ ($3.25 \times 10^{-7}$) | −0.0513 (0.0710) |
| Observations | 125 | 125 |
| Groups | 5 | 5 |
| Wald $\chi$-statistics(Prob > $\chi^2$) | 414.74 (0.000) | 400.16 (0.007) |
| Root mean squared error (RMSE) | 0.0292 | 0.0172 |

Note: Standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

**Table 7.** Results of Dumitrescu–Hurlin panel causality test.

| Null Hypothesis: | W-Stat. | Zbar-Stat. | Prob. |
|---|---|---|---|
| $LnCO_2 \neq LnGI$ | 3.3566 | 3.7260 | 0.0002 |
| $LnGI \neq LnCO_2$ | 4.4723 | 5.4902 | 0.0000 |
| $LnGDP \neq Ln\ CO_2$ | 1.7206 | 1.1394 | 0.2545 |
| $LnCO_2 \neq LnGDP$ | 2.6479 | 2.6055 | 0.0092 |
| $LnFDI \neq LnCO_2$ | 1.1940 | 0.3067 | 0.7591 |
| $LnCO_2 \neq LnFDI$ | 1.6545 | 1.0349 | 0.3007 |
| $LnTO \neq LnCO_2$ | 5.1708 | 6.5946 | 0.0000 |
| $LnCO_2 \neq LnTO$ | 3.5912 | 4.0970 | 0.0000 |
| $LnEU \neq LnCO_2$ | 6.7030 | 9.0172 | 0.0000 |
| $LnCO_2 \neq LnEU$ | 2.5524 | 2.4546 | 0.0141 |
| $LnUR \neq LnCO_2$ | 1.8599 | 1.3596 | 0.1740 |
| $LnCO_2 \neq LnUR$ | 3.8227 | 4.4631 | 0.0000 |

Note: The Dumitrescu–Hurlin test is estimated with 1 lag and Zbar-statistics, LnA $\neq$ LnB suggests that LnAdoes not homogeneously cause LnB.

## 5. Conclusions and Policy Implications

### *5.1. Conclusions*

Due to increased environmental degradation issues, researchers around the globe have conducted in-depth research on various causes and effects of environmental degradation, determinants of environmental pollution, and economic impacts of environmental contamination. Numerous studies have highlighted the relationship of FDI, economic growth, trade openness, urbanization, and energy consumption with environmental sustainability in the available literature. However, very rare studies have explored the relationship between green innovation and environmental quality and none of them have investigated a similar relationship in the case of BRICS countries. With this in mind, we investigated the nexus among FDI, green innovation, and environmental quality in the case of BRICS countries for 1990–2014. We used the latest econometric techniques for the study's empirical analysis. We conducted the cross-sectional dependence test, which shows a solid cross-sectional dependence among the variables of the BRICS panel. After confirming cross-sectional dependence, we undertook Westerlund, Kao, and Pedroni cointegration tests. The results from cointegration tests confirmed the cointegration among the selected variables of the study. After confirming cointegration among variables, we checked the long-term relationship between the study's variables using the AMG model. The results of AMG estimations depict that foreign direct investment has a significantly positive impact on the environment of BRICS economies and is potentially harmful to the natural environment. Furthermore, empirical results of this study indicate that energy use also negatively impacts environmental quality. In addition, the findings of the study show that GDP enhances $CO_2$ emissions in BRICS countries. Moreover, the empirical outcomes of this study verified that green innovation has a significant inverse impact on $CO_2$ emissions in BRICS countries. However, study outcomes found an insignificant relationship between urbanization and trade openness in the case of BRICS countries. To verify the robustness of the model, we examined our data through CCEMG estimation methods, and the results were the same as for AMG estimators. We also investigated causality directions of the variables through the Dumitrescu–Hurlin panel causality tests. The results indicate bidirectional causalities between $CO_2$ emissions and green innovation, trade openness and $CO_2$ emissions, energy useand $CO_2$ emissions, and urbanization and $CO_2$ emissions. We detected a one-way causality from $CO_2$ emissions to GDP and $CO_2$ emissions to urbanization. This study provides substantial empirical evidence on how FDI and green innovation impact environmental quality in BRICS countries. The findings and recommended policy measures can provide valuable guidelines for these countries' policy measures to improve environmental quality through green innovation and FDI in environmentally friendly projects.

### *5.2. Policy Implications*

Based on the findings of this study, we propose the following policy measures for governments and policymaking bodies to combat the environmental degradation issues in BRICS countries. The main results of this study indicate that FDI, energy use, and economic growth result in spurring $CO_2$ emissions in the BRICS economies. Therefore, these countries should reconsider their economic and environmental policies. These countries should attract more FDI in alternative/renewable energy projects through tax incentives. In other words, energy-efficient and low-carbon foreign investments should be encouraged in the region. In addition, the study outcomes reveal that energy use increases $CO_2$ emissions; therefore, countries should promote the use and generation of renewable energies and discourage non-renewable energies by imposing taxes. Moreover, green innovation depresses $CO_2$ emissions in BRICS countries; therefore, policymakers and governments should encourage green innovation by spending more on research and development and green technology.

### *5.3. Limitations of the Study*

This study has investigated the association among FDI, green innovation, and environmental quality on one group of countries, the BRICS. Further studies could be conducted on a similar topic in different regions and countries. Moreover, comparative studies on similar issues, such as developed and developing economies, can also be undertaken to understand the subject matter more clearly. Furthermore, different empirical methods and updated data could be used in the future for analysis.

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