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Investigating the Relationship and Impact of Environmental Governance, Green Goods, Non-Green Goods and Eco-Innovation on Material Footprint and Renewable Energy in the BRICS Group

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Abstract: The global climate is undergoing a significant and unprecedented transformation. The phenomenon presents a significant peril to the well-being of the human population, biodiversity, and the overall stability of the global ecosystem. This article explores the relationship and impact between environmental governance, green goods, non-green goods, and eco-innovation on material footprint and renewable energy for the BRICS countries from 2000 to 2019. We apply the FGLS and PCSE approaches to estimate the relationships, and the Dumitrescu and Hurlin test to ascertain causality. The study reveals that eco-innovation and environmental governance produce a statistically significant positive relationship with both material footprint and renewable energy consumption. Economic growth generates an insignificantly positive link with material footprint and renewable energy use. The findings also illustrate that non-green goods generate a significantly negative association with both material footprint and green energy use. Green goods depict a significant and positive relationship with material footprint, but a significantly negative relationship with renewable energy consumption in the BRICS situation. The causality results demonstrate a bi-directional causality association between non-green goods and material footprint, green goods and material footprint, renewable energy use and eco-innovation, renewable energy consumption and environmental governance, and renewable energy use and green goods. Moreover, a uni-directional causality relationship running from eco-innovation to material footprint, environmental governance to material footprint, non-green goods to renewable energy consumption, material footprint to economic development, and renewable energy consumption to economic growth is established. The study's findings provide light on the association between the parameters and unsustainable and sustainable green practices on material footprint and renewable energy consumption, respectively, within the BRICS framework. These findings offer useful insights for policymakers, emphasizing the need for nations to work together in order to create a balanced and harmonious relationship between economic progress and environmental conservation from an emerging economy scale.

Keywords: environmental governance; green goods; non-green goods; eco-innovation; material footprint; renewable energy consumption

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1. Introduction

Over the past decade, detrimental effects of ecological degradation have been frequently observed, including rapid depletion of resources, extensive degradation of biodiversity, hazardous carbon emissions, extreme heatwaves, drought expansion, and food scarcity [1]. There is a contention that the escalating vulnerability of ecosystems can be ascribed to detrimental anthropogenic activities, such as the proliferation of human population, substantial economic expansion, heavy dependence on fossil fuels, and the depletion of natural resources [2–4]. In this context, the Sustainable Development Goals (SDGs), particularly SDG-12 and SDG-13, emphasize the significance of sustainable production and consumption as well as the urgent need for climate action in both emerging and industrialized nations. Among the world's leading economies, the BRICS region stands out as the most vulnerable area grappling with significant environmental concerns. In light of these problems, policymakers and scholars within the BRICS community are implementing steps to address them, while also formulating policies. These actions include the adoption of effective resource management strategies and the integration of green technologies [5,6]. These policies serve as a guide towards achieving sustainable development.

Clearly, the natural environment has been swiftly deteriorating on a global scale as a result of global warming. In this particular scenario, the utilization of traditional products, the non-green goods, has a dual negative impact, including both the environment and human well-being. The global impact of these non-sustainable products is increasingly shifting towards the adoption of environmentally friendly alternatives, including goods, processes, and technologies. Therefore, products that are considered environmentally and socially responsible are commonly referred to as "green goods". One successful approach to encourage people to shift from conventional to green goods purchases is by implementing a robust environmental governance mechanism [7,8]. Environmental governance refers to the comprehensive framework encompassing regulations, methodologies, and organizational structures that dictate the manner in which human beings engage with the natural environment [9]. The concept encompasses the decision-making procedures that govern and oversee the environment and its natural resources. The rapid advancement of the economy and technology has resulted in increased comfort in human existence but has also given rise to several environmental challenges such as global warming, air pollution, and climate change.

Green products are organic, non-toxic, environmentally compatible, and can even be composed primarily of recycled materials [10]. However, numerous human activities exert a significant impact on the environment as shown by the frequent occurrence of several environmental issues that can be identified, including the accelerated utilization of natural resources, the degradation of the ozone layer, and the release of carbon [11]. Therefore, effective environmental governance takes into account the involvement of all stakeholders who have an impact on the environment. The use of collaborative approaches has the potential to mitigate conflicts and disputes among nations or interested parties regarding the utilization of natural resources, hence fostering trust and enhancing security.

Therefore, it is critical to emphasize that eco-innovation must be integrated into an organizational framework that fosters conducive circumstances for the development of environmental capabilities capable of producing resolutions for sustainability issues [4,12]. Therefore, the implementation of robust environmental governance frameworks can create a conducive climate for reducing the excessive depletion of natural resources and promoting the widespread integration of green energy technology [13]. Hence, by exerting its impact on the processes of knowledge acquisition, knowledge expression, and knowledge systematization, environmental governance establishes a framework that facilitates the enhancement of dynamic capabilities [14]. This framework enables eco-innovators to cultivate their abilities in generating environmentally conscious knowledge-driven solutions to address environmental issues. This article aims to investigate the relationship and impact of environmental governance, green goods, non-green goods, and eco-innovation on material footprint and renewable energy consumption within the context of the BRICS countries.

The BRICS group (Brazil, Russia, India, China, and South Africa) is an emerging economy coalition that recognizes the criticality of environmental preservation and efficient utilization of natural resources [15]. The rising markets in question have witnessed remarkable economic expansion since the onset of the 21st century and possess significant capabilities for industrial and service sector advancement. The BRICS group's economic expansion over the past two decades has been accompanied by a notable lack of focus on environmental concerns [16]. The geopolitical influences of these nations are robust, and their emissions histories can exert a substantial impact on the global temperature.

This is particularly noteworthy considering that these five nations collectively encompass roughly 30% of the world's territorial terrain and approximately 50% of the worldwide population [15].

A number of regulations exist in these nations that influence their decisions concerning the subject. Brazil's National Climate Change Policy of 2008 establishes Brazil's objectives for mitigating greenhouse gas emissions and fostering sustainable development. Therefore, in 2008, the Brazilian Government initiated the implementation of the National Climate Change Plan. The strategy aims to decrease greenhouse gas emissions primarily through mitigation and adaptation measures, promotion of renewable energy, reduction in deforestation and forest loss, and research and development. The plan outlines specific goals, including a 20% increase in urban waste recycling by 2015, an 80% reduction in deforestation rate by 2020, an annual 11% increase in domestic ethanol consumption by 2020, and a target of 11.4% contribution of sugarcane biogases to the country's total electricity supply by 2030 [17]. Furthermore, China implemented the Ecological Civilization Strategy in 2015, a comprehensive and enduring initiative aimed at advancing environmental conservation and sustainability inside the country. The ecological civilization strategy has the potential to provide regional and global benefits, such as supporting United Nations SDG 2030 initiatives at both global and country levels, as well as across different sectors. Moreover, it aims to utilize the concept of ecological civilization to enhance cooperation and expedite progress by leveraging the various international agreements on environmental issues such as climate change, biodiversity, desertification, and oceans, among others, in conjunction with greening the Belt and Road Initiative (a global infrastructure development strategy initiated in 2013. Additionally, the strategy supported establishing guidelines, procurement policies, and other mechanisms to promote environmentally friendly supply chains. Other focuses involved the engagement of multinational corporations and Chinese firms in both international and domestic contexts, namely in the areas of corporate social responsibility and the promotion of international collaboration in green technology through advancements in science and technology [18].

In addition, India has implemented the National Clean Air Programme of 2019, a comprehensive initiative designed to enhance air quality in Indian cities by mitigating emissions from diverse sources. The program focuses on expanding and enhancing an efficient and effective network for monitoring ambient air quality throughout the country, with the goal of establishing a comprehensive and dependable database. Furthermore, the program aims to raise public awareness and promote capacity-building measures, including the dissemination of data and outreach programs, to encourage inclusive public participation. Additionally, the program seeks to ensure the availability of well-trained personnel and adequate infrastructure to address air pollution concerns [19]. Also, the National Waste Management Strategy of 2019 in South Africa holds comparable significance. This document presents South Africa's comprehensive approach to effectively and responsibly handling waste. This initiative was implemented to align the strategic approach to waste management with the goals and directives of the Sustainable Development Goals 2030 and South Africa's National Development Plan: Vision 2030. It clearly identifies waste management as a crucial aspect of South Africa's economy and social structure. Additionally, it integrates and creates a supportive environment for the DEFF's 2017 Chemicals and Waste Economy Phakisa and the government's 2019 Good Green Deeds Programme [20]. The Environmental Protection Law of 2012 in Russia defines the legal structure for safeguarding the environment in the country. This legislation is very consequential and has had a profound influence on environmental policy in Russia.

This research makes significant contributions to the existing body of knowledge in several key areas. To begin with, the present study employed a comprehensive metric of material footprint to account for environmental degradation, in contrast to the conventional metric of carbon emission which can only approximate the extent of air pollution. The material footprint measure is widely recognized as an effective indicator of ecological degradation. It takes into account the allocation of extracted raw materials to fulfil the final demand of an economy, which includes the raw materials used in the production of imported products. Second, a significant portion of the current body of literature has focused on the measurement of production-based material footprint, neglecting the examination of the true environmental consequences associated with the consumption-based utilization of natural resources in both export and import activities. In their study, Ref. [21] devised a trade-adjusted metric that incorporates the impact on natural resources resulting from real consumption patterns, accounting for adjustments made to account for traded resources, which is also employed in this paper.

Third, the current investigation focuses exclusively on examining the contemporary characteristics of four key factors: (a) eco-innovation, which pertains to the quantity of patents filed for carbon capture and storage technologies; (b) environmental policy stringency, which refers to the index measuring the level of strictness in environmental policies within a specific region; (c) non-green goods, denoting non-environmental products derived from fossil fuels; and (d) green goods, representing environmentally friendly products derived from biomass. In this light, the study has made a valuable contribution by elucidating the cumulative influence of unsustainable and sustainable green initiatives on material footprint and renewable energy consumption within the BRICS framework, marking the first instance of such analysis. Thus, fourth, this study aims to expand the existing research on material footprint and green energy use by offering further insights into the various elements that influence these phenomena. The study will utilize comprehensive variables and employ a cross-country panel analysis.

Fifth, to the best of the authors' knowledge, this is the first study in case of the BRICS alliance exploring the effects of environmental governance, green goods, non-green goods, and eco-innovation on both material footprint and renewable energy consumption. Sixth, prior studies have overlooked the consideration of conditional dependence (CD) in the examination of environmental conditions in BRICS nations. To address this gap, we employ the method of feasible generalized least squares (FGLS) and incorporate panel corrected standard errors (PCSE) as a means to account for probable CD. These approaches also serve as robustness checks for our analysis. Furthermore, it should be noted that both the Panel Corrected Standard Errors (PCSE) and the Feasible Generalized Least Squares (FGLS) methods have the ability to effectively handle the issues of autocorrelation, heteroscedasticity, and simultaneous correlation.

The organizational structure of this paper is as follows. In the following section, an examination of the pertinent literature pertaining to the topic is conducted. Section 3 presents the data and econometric tools of this paper. Section 4 provides a candid presentation of the research results and associated discussion. The implications of the study derived from the results are presented in Section 5. Section 6 of this study provides an overview of the findings and draws conclusions based on the analysis.

2. Literature Review

This section aims to provide a comprehensive analysis of current scholarly research pertaining to the relationship between diverse environmental, political, economic, financial, energy-related aspects, and both material footprint and renewable energy consumption.

2.1. Relations Involving Variables in the Perspective of Material Footprint

Research on the "Belt and Road" countries [22] proves that the rise in the material footprint in these nations may be mostly attributed to changes in income. Moreover, the observed intensity effect impeded the growth of material footprint, and the examination of decoupling indicated that the collective condition of the Belt and Road (B&R) countries exhibited a lack of decoupling. In another study the findings indicate that China's per capita material footprint increased by approximately 20% between 2007 and 2012 [23], which was consistent with its HDI. This phenomenon is particularly prevalent in economically disadvantaged provinces, and the primary driver of China's material footprint was capital investments related to construction and manufacturing, rather than a consumption-driven demand. Likewise, Ref. [2] highlights that based on the analysis conducted using the material footprint indicator the Environmental Kuznets Curve (EKC) hypothesis is validated for four Asian subregions (West, South, East, and Southeast Asian nations). Furthermore, the overarching processes of globalization and urbanization contribute to the amplification of material footprint in these Asian countries. In addition, findings from the long-term analysis in [5] suggest that the environmental quality in BRICS countries has been negatively affected by factors such as economic development, natural resource utilization, the adoption of renewable energy sources, and the process of urbanization, since they heighten the material footprint. Nevertheless, the enhancement of environmental quality was attributed to the positive impact of foreign trade and human capital.

2.2. Relations Involving Variables in the Perspective of Renewable Energy

Ref. [24]'s empirical findings for the Sub-Saharan African economies show there is a short-term increase of 0.128% in the level of renewable energy consumption for every 1% rise in economic activity, and the long run it is observed that economic expansion has a dampening effect on the consumption of renewable energy. Moreover, causality results demonstrate a uni-directional causality, specifically from economic growth towards renewable energy usage. A feedback causation relationship was seen between urbanization and renewable energy. Similarly, research on 21 African countries [6] posits that countries with a higher per capita gross domestic product and a higher Human Development Index have a lower proportion of renewable energy in their national grid. Conversely, a positive relationship has been shown between an upsurge in foreign direct investment and an enhanced integration of renewable energy sources. The integration level of renewable energy sources is not directly influenced by the degree of democracy (as assessed by the political rights and civil liberties ratings). Additionally, a survey across a sample of 43 industrialized and developing nations throughout the period of 2000–2015 [25] suggests that an amelioration in wealth inequality will have a positive impact on the adoption and utilization of renewable energy sources. In addition, the implementation of measures to combat corruption and reduce carbon emissions is expected to contribute to the growth of renewable energy usage. Furthermore, Ref. [3] confirms that factors such as political stability, governance effectiveness, and financial development play crucial roles in facilitating the growth and advancement of renewable energy generation within the nine Middle East and North Africa (MENA) countries.

The extant body of literature lacks comprehensive analysis regarding the interplay between material footprint, renewable energy, environmental governance, green goods, non-green goods, and eco-innovation in the BRICS nations. First, the accessibility of comprehensive and dependable data pertaining to material footprint, green goods, non-green goods, environmental governance and eco-innovation in various countries is frequently constrained and insufficient. Therefore, the presence of these data inside the BRICS context facilitates the execution of a comprehensive empirical investigation and the formulation of strong and reliable findings.

Second, there is a common assumption that the environmental impact of green goods and non-green goods can be easily discerned, with green goods being perceived as more ecologically friendly and non-green goods as more detrimental to the environment. Nevertheless, it is crucial to acknowledge that the actual situation is considerably more intricate, necessitating further comprehensive investigations to evaluate the genuine environmental impact of these commodities on indicators like material footprint and utilization of green energy. This evaluation also encompasses the addition of various significant factors, including environmental governance, eco-innovation, and economic growth. Thirdly, the BRICS group, comprising significant emerging and developing nations, needs a comparative analysis with other developed areas or countries that possess distinct economic and environmental circumstances. This analysis can offer a more comprehensive understanding of the various aspects that impact environmental sustainability in developing nations. The subsequent section of this study undertakes an analysis of the data and techniques employed.

3. Data and Research Methodology

3.1. Data Description

The objective of this research endeavour is to examine the relationship and impact of environmental governance, green products, non-green products, and eco-innovation on the material footprint and renewable energy use of the BRICS nations. The empirical investigation utilized panel data spanning from 2000 to 2019 and employed robust econometric methodologies. A detailed analysis of the data is presented in Table 1 below:

Table 1. Brief analysis of data.

Variable	Definition	Unit	Source
LogMAFT	Material Footprint	Material Footprint per capita trade adjusted	Global Material Flows Database
LogGEN	Renewable Energy	Renewable energy (% of total energy consumption)	WDI Database
LogECO	Eco-innovation	Annual patents filed for carbon capture and storage technologies	Our World in Data
LogRDN	Non-Green Goods	Non-environmental goods—products from fossils (exports + imports)	Global Material Flows Database
LogGD	Green Goods	Environmental goods—products from biomass (exports + imports)	Global Material Flows Database
LogY	Economic Growth	GDP per capita (constant 2015 US$)	WDI Database
LogESTR	Environmental Governance	Environmental Stringency Index	OECD Database

3.2. Econometric Tool

(a) *The Feasible Generalized Least Squares (FGLS) method*

This paper employs both the Feasible Generalized Least Squares (FGLS) and the Panel Corrected Standard Errors (PCSE) models to analyse the data. FGLS enables the estimation of models that account for autocorrelation within panels, as well as cross-sectional correlation and heteroskedasticity across panels [26]. The utilization of the Panel Corrected Standard Errors (PCSE) model is employed to effectively tackle the challenges arising from cross-sectional dependence, groupwise heteroscedasticity, and autocorrelation. The presence of autocorrelation and heteroscedasticity in a dataset can result in suboptimal estimates. Therefore, it is necessary to adequately handle these issues using Panel Corrected Standard Errors (PCSE). The technique has been utilized by [27] to tackle comparable concerns. This model is specifically designed to address the challenges posed by panel data with even a short time dimension and cross-sectional dependence, as highlighted by [28].

Based on the studies conducted by [27,29,30], the postulated generalised link can be expressed as follows.

$$\text{MAFT} = \text{f(ESTR, GD, RDN, ECO, Y)} \quad (1)$$

$$\text{GEN} = \text{f(ESTR, GD, RDN, ECO, Y)} \quad (2)$$

Therefore, the model is designed to incorporate the given specification as follows:

$$\text{LogMAFT}_{it} = \beta_0 + \beta_1\text{LogESTR}_{it} + \beta_2\text{LogGD}_{it} + \beta_3\text{LogRDN}_{it} + \beta_4\text{LogECO}_{it} + \beta_5 Log\text{Y}_{it} + \varepsilon_{it} \quad (3)$$

$$\text{LogGEN}_{it} = \beta_0 + \beta_1\text{LogESTR}_{it} + \beta_2\text{LogGD}_{it} + \beta_3\text{LogRDN}_{it} + \beta_4\text{LogECO}_{it} + \beta_5\text{LogY}_{it} + \varepsilon_{it} \quad (4)$$

According to [31], the Feasible Generalized Least Squares (FGLS) method is considered to be a reliable approach for panel data analysis when the panel structure is characterized by a large number of time periods (T) and a small number of cross-sectional units (N). On the other hand, the Panel Corrected Standard Errors (PCSE) method is recommended for panel data analysis when the panel structure is characterized by a large number of cross-sectional units (N) and a small number of time periods (T). On that note, this paper prefers outcomes of the FGLS approach. The confirmation of the robustness of the results is achieved by the utilization of the Panel Corrected Standard Errors (PCSE) estimation approach.

(b) *Dumitrescu and Hurlin Panel Causality approach*

The panel causality test that [32] introduced is utilized in this article. Utilizing panel causality tests will aid the paper in its comprehension of causality. The framework of this type of test is a clear and unambiguous extension of [33] non-causality test for panelised heterogeneous data structures with fixed coefficients. Additionally, the analysis takes into account two types of heterogeneity: the heterogeneity of the causality associations and the heterogeneity of the regression equation utilized to examine Granger causality. Therefore, this article initially considers the subsequent framework:

$$y_{i,t}= \alpha_i+\sum_{k=1}^{K} \gamma_i^{(k)} y_{i,t-k}+\sum_{k=1}^{K} \beta_i^{(k)} y_{i,t-k}+\varepsilon_{i,t},\ i = 1,2,\ldots\ldots,N;\ t = 1,2,\ldots\ldots,T \quad (5)$$

Two stationary variables known to N individuals during T periods are denoted by x and y in this instance. In the time dimension specification, both $\beta_i = (\beta_i^{(1)}, \ldots.., \beta_i^{k})^t$ and individual effects α_i are considered to be constant. Additionally, it is presumed that the lag orders of K are consistent across the entire cross-section of the penalized data being examined in the study. Additionally, it is acceptable for the autoregressive parameters $\gamma_i^{(k)}$ and the regression coefficients $\beta_i^{(k)}$ to vary among groups.

This testing strategy assumes that the null hypothesis posits the absence of a causal relationship for all available units (x and y) in the panel data. A rejection of H_o would thus indicate the presence of causality between x and y, according to the study. It is also possible to examine causality in the opposite direction (bidirectional causality), also known as feedback impacts, by exchanging x and y. Often referred to as the Homogenous Non-Causality (HNC) hypothesis, this presumption is defined as follows:

$$H_o\colon \beta_i= 0,\ \forall i = 1,\ldots\ldots,N \quad (6)$$

The Heterogeneous Non-Causality (HENC) hypothesis is defined as the alternative hypothesis. Consequently, two subcategories of cross-section units are permissible in accordance with the HENC hypothesis.

One potential drawback is that, while the initial model posits a causal relationship from x to y, its regression framework does not adequately support this conclusion. Conversely, the second subcategory emphasizes the absence of a causal relationship between variable x and variable y. A heterogeneous panelised data framework is being considered, which consists of constant coefficients over time in relation to this particular group. These are the formulations of the alternative hypothesis:

$$H_1\colon \beta_i = 0,\ \forall i = 1,\ldots\ldots,N_1 \quad (7)$$

$$\beta_i \neq\ 0,\ \forall i = N_1 + 1,\ \ldots\ldots,\ N \quad (8)$$

Furthermore, it is postulated that β_i may vary among groups and that there exist N_1 (N) distinct procedures that lack a causal relationship from x to y. Furthermore, the fact that N_1 is unknown allows for the condition $0 \leq N_1/N < 1$. In this vein, the following describes the average statistic $W_{N,\,T}^{HNC}$ that is associated with the null HNC hypothesis:

$$W_{N,T}^{HNC}= \frac{1}{N}\sum_{i=1}^{N} W_{i,T} \quad (9)$$

Therefore, in accordance with the individual test hypothesis H_o: $\beta_i = 0$, $W_{i,\ T}$ represents the Wald statistics for the ith cross-section unit. We denote Z_i = [e: Y_i: X_i] to assume the matrix, (T, 2K + 1), in which e shows a (T,1) unit vector plus $Y_i = [y_i^{(1)}: y_i^{(2)}: \ldots\ldots: y_i^{(K)}]$, $X_i = [x_i^{(1)}: x_i^{(2)}: \ldots\ldots: x_i^{(K)}]$. $\ddot{\theta}_i = (\alpha_i \gamma_i' \beta_i')$ symbolises vector of variables of the model. As well, this article let $R = [0{:}1_K]$ be a (K, 2K + 1) matrix.

Detailed below is the Wald statistical estimate $W_{i,T}$ that corresponds to the individual tests H_o: $\beta_i = 0$ for each i = 1, . . ., N:

$$W_{i,T} = \ddot{\theta}_i' R' \left[{}_{i}^{2} R \left(Z_i' Z_i \right)^{-} 1 R' \right]^{-1} R \ddot{\theta}_i \tag{10}$$

With respect to the hull hypothesis of non-causality, each Wald statistic value corresponds to a K-degrees-of-freedom chi-squared distribution for $T \rightarrow \infty$.

$$W_{i,T} \rightarrow \chi^2(K),\ \forall i = 1, \ldots\ldots, N$$

The expression for the standardized test statistic estimates $Z_{N,\ T}^{HNC}$ for T, $N \rightarrow \infty$ is as follows:

$$Z_{N,\ T}^{HNC} = \sqrt{\frac{N}{2K}} \left(W_{N,\ T}^{HNC} - K \right) \rightarrow N(0,1) \tag{11}$$

Furthermore, the formula for the standardized test estimate $\check{Z}_N^{HNC}$ for fixed T samples is as follows:

$$\check{Z}_N^{HNC} = \sqrt{\frac{N}{2K}} \times \frac{(T-2K-5)}{(T-K-3)} \times \left[\frac{(T-2K-3)}{(T-2K-1)} W_{N,T}^{HNC} - K \right] \rightarrow N(0,1) \tag{12}$$

Therefore, observing regression (11) and (12), $W_{N,T}^{HNC} = (1/\mathrm{N}) \sum_{i=1}^{N} W_{i,T}$. The [32] approach is especially significant and relevant in cases where the error terms exhibit cross-sectional dependence. The test is also applicable to heterogeneous and balanced panels in which the time period (T) is greater than the number of cross sections (N).

4. Results and Discussion

This section begins by describing the characteristics of the data. Subsequently, a panel unit root test is conducted on the research samples, followed by the execution of the panel cointegration test. This study utilizes the Feasible Generalized Least Squares (FGLS) and Panel Corrected Standard Errors (PCSE) econometric models to examine the impact of various variables on renewable energy and material footprint in the context of the BRICS countries.

Descriptive statistics regarding the data are presented in Table 2. LogMAFT, LogGEN, LogECO, LogRDN, LogGD, LogY, and LogESTR are the seven variables that make up the data. Except for LogY, which is significantly skewed to the left, the table indicates that the data are often somewhat skewed to the left. This indicates that, in the case of LogY, there are more extreme values at the high end of the distribution than at the low end. Except for LogY, which has a high kurtosis, the data have a generally low kurtosis. This indicates that, apart from LogY, which has a higher peaked distribution, the data are usually bell-shaped. With the exception of LogESTR, which has a negative mean value, all of the variables have positive means. This indicates that, apart from LogESTR, the data are skewed to the right in general. Therefore, in the context of the BRICS nations, we can emphasize for LogESTR that environmental regulations are making few offenders pay for directly or indirectly harming the environment. With the exception of LogECO and LogY, which have higher standard deviations, all of the variables have relatively small standard deviations. This indicates that compared to the data for the other variables, the data for these variables are more dispersed.

The panel unit root test outcomes are presented in Table 3 of the article. Some of the commonly used unit root tests to check for stationarity in time series data are the

Fisher augmented Dickey-Fuller (ADF), Harris-Tzavalis, and Im-Pesaran-Shin tests. The Harris-Tzavalis and Im-Pesaran-Shin tests are non-parametric, but the Fisher (ADF) test is parametric [34–36]. Every variable is non-stationary at the level but stationary at the first difference, according to the consistent results of the three tests. Therefore, it is evident from the results of these unit root tests that none of the variables support the null hypothesis that a time series remains constant at level I (0). This suggests that these variables are stationary at the first difference, I (1), as opposed to elsewhere.

Table 2. Presenting the descriptive statistics of the data.

Variable	Mean	Minimum	Maximum	Std.Dev.	Skewness	Kurtosis
LogMAFT	0.9722	0.5257	1.3416	0.2335	−0.1746	2.1897
LogGEN	1.1899	0.5024	1.6895	0.4210	−0.3573	1.7418
LogECO	1.2349	0	2.7482	0.7569	−0.0158	2.4735
LogRDN	7.6813	6.8729	8.3098	0.4210	−0.2971	1.7585
LogGD	6.9439	6.0867	7.6784	0.4184	−0.1642	2.0822
LogY	14.2813	7.9765	14.9831	1.1234	−3.6376	18.275
LogESTR	−0.0878	−0.7696	0.4683	0.3291	−0.2349	2.3444

Table 3. Panel Unit Roots Test Results.

	At Level			At 1st Difference		
Variable	**Fisher ADF Statistic**	**Harris-Tzavalis Statistic**	**Im-Pesaran-Shin Statistic**	**Fisher ADF Statistic**	**Harris-Tzavalis Statistic**	**Im-Pesaran-Shin Statistic**
LogMAFT	−0.1901	0.5814	0.0736	10.5022 ***	−12.3364 ***	−3.7915 ***
LogGEN	4.0227 ***	−0.0520	−2.0799 **	10.4642 ***	−8.3551 ***	−2.4048 ***
LogECO	3.1808 ***	−3.9997 ***	−1.5967 *	23.1481 ***	−18.4302 ***	−4.6273 ***
LogRDN	−0.4714	0.5060	−0.0530	17.4661 ***	−17.1172 ***	−4.5179 ***
LogGD	3.9643 ***	0.9347	−1.1487	11.5741 ***	−10.5377 ***	−3.9169 ***
LogY	12.0560 ***	−14.6070 ***	−4.3228 ***	53.7579 ***	−19.6095 ***	−6.6160 ***
LogESTR	−1.1018	0.1262	0.3740	13.8666 ***	−11.4665 ***	−4.5915 ***

Notes: ***, **, and * illustrates that the coefficients are significant at the 1%, 5% and 10% level of significance, respectively.

The CD test outcomes pertaining to each variable are detailed in Table 4. With the exception of LogY-economic growth (which is weak), we have substantial evidence to refute the cross-sectional independence null hypothesis for every variable under analysis. Stated differently, there is cross-sectional dependence among material footprint, renewable energy consumption, eco-innovation, non-green goods, green goods, economic growth, and environmental governance. Moreover, at the 1% significance level, the slope homogeneity tests presented in Table 4 are statistically significant. This indicates that when material footprint and renewable energy use are dependent variables in the regression, the panel rejected the slope homogeneity assumption. Slope heterogeneity is therefore appropriate for all regressions in the panel. It is important to take slope homogeneity and cross-section dependency into account when making consistent and accurate predictions. Thus, for each of the distinct panel time-series data, this study applies the CADF and the CIPS panel unit root tests.

The CADF test estimates proposed by [37] are presented in Table 5. According to the CADF estimates, a second-generation unit root test that considers cross-section dependency, all the variables are either stationary or only stationary. The series becomes stationary after taking the first difference of all the variables, I (1). Additionally, Table 5 shows that the first differenced values for the CIPS test are less than the critical values, which suggests that all of the parameters are stationary at the first difference. As a result, the findings of the CADF and CIPS tests concur for this paper. Therefore, it is possible to determine if the stationary variables in I (1) have a cointegration relationship.

Table 4. Cross-sectional dependence (CD) output.

Variables	$CD_{Pesaran}$ Test (2004)	
	Statistic	*p*-Value
LogMAFT	4.81 ***	0.0000
LogGEN	4.61 ***	0.0000
LogECO	6.81 ***	0.0000
LogRDN	12.30 ***	0.0000
LogGD	12.69 ***	0.0000
LogY	−0.64	0.5200
LogESTR	8.32 ***	0.0000
Slope-homogeneity—with LogMAFT as the dependent term		
Delta	6.006 ***	*p*-value = 0.000
Adj. Delta	7.450 ***	*p*-value = 0.000
Slope-homogeneity—with LogGEN as the dependent term		
Delta	3.931 ***	*p*-value = 0.000
Adj. Delta	4.875 ***	*p*-value = 0.000

Notes: [1] *** indicate that the coefficients are significant at the 1% level of significance.

Table 5. CADF and CIPS tests results.

Tests	CADF Tests		CIPS Tests	
Variables	Level (Constant and Trend)	First Difference (Constant and Trend)	Level (Constant and Trend)	First Difference (Constant and Trend)
LogMAFT	−1.449 *	−1.768 **	−2.473	−3.482
LogGEN	0.323	−1.438 *	−1.905	−3.440
LogECO	−0.506	−2.397 ***	−2.908	−4.281
LogRDN	0.855	−4.078 ***	−1.791	−3.919
LogGD	0.190	−4.490 ***	−2.373	−4.308
LogY	0.757	−3.648 ***	−3.560	−5.842
LogESTR	0.812	−3.335 ***	−1.579	−3.787

Notes: ***, **, and * indicate that the coefficients are significant at the 1%, 5%, and 10% level of significance, respectively, for the CADF tests. For the CIPS tests, the critical values at 1%, 5%, and 10% are −2.74, −2.88, and −3.15, respectively.

Table 6 presents the outcomes of panel cointegration tests conducted with the Stata code xtpedroni, which was originally suggested by [38]. This command enables the execution of Pedroni's seven tests using non-stationary regressors in a heterogeneous panel. Two categories, namely "group" and "panel", comprise these seven examinations. The utilization of Pedroni tests facilitates the evaluation of cointegration among variables, thus aiding in the detection of possible long-term associations within the panel data. This particular stage is of the utmost importance in order to comprehend the interconnections and fundamental dynamics of the variables being examined. As a result, the majority of test statistics in the procedure of [38] reject the null hypothesis that there is no cointegration for both equations (LogMAFT and LogGEN regressions). Simultaneously, the absolute values of various Pedroni statistics are upper to 0.15, indicating that the null hypothesis of absence of cointegration for both equations could be rejected. Additionally, at the 1% significance level, the outcomes of the [39] test indicate that both models are statistically significant. This indicates that variables occupy a shared long-term equilibrium. In general, the results of the Pedroni and Kao cointegration tests strongly support the existence of a long-term relationship.

Table 6. Pedroni and Kao tests results.

Regression	Pedroni Test			Kao Test
	Test Stats.	**Panel Stats.**	**Group Stats.**	***t*-Tests**
LogMAFT	V-stat	0.1733		−2.473947 ***
	Rho-stat	1.1170	2.065	
	T-stat	−3.485	−3.472	
	ADF-stat	−2.990	−2.685	
LogGEN	V-stat	−0.3388		−3.150173 ***
	Rho-stat	1.8430	2.526	
	T-stat	−0.252	−1.511	
	ADF-stat	0.1503	−0.6118	

Notes: To retrieve the Pedroni test statistics, use the Stata command "xtpedroni". For Pedroni tests, all test statistics are distributed N(0,1), under a null of no cointegration, and diverge to negative infinity (save for panel v). *** indicate that the coefficients are significant at the 1% level of significance.

The empirical outcomes of this research are delineated in this segment. Table 7 presents the empirical results of FGLS and PCSE when material footprint is the dependent variable. The primary significance of the FGLS findings lies in the PCSE results, which are merely crucial for conducting a robustness check. The study reveals that eco-innovation establishes a statistically significant positive relationship with material footprint in this regard. Therefore, this suggests that the adoption and implementation of eco-innovations tend to result in a rise in the aggregate material footprint of the economies comprising the BRICS group. Thus, it is possible to indicate that this observation may have several possible explanations in the context of the BRICS nations. Firstly, where increased efficacy or decreased costs resulting from BRICS eco-innovations stimulate greater utilization of products or services, it is possible that eco-innovations are causing an increase in consumption patterns. Furthermore, if BRICS eco-innovations provide environmental benefits in other domains, it is possible that they entail the substitution of current materials with those that have a greater material footprint. Additionally, it is worth noting that while BRICS eco-innovations may concentrate on particular facets of the material footprint associated with the lifecycle of a product or service (e.g., extraction, production, transportation, and disposal), the material footprint as a whole may remain substantial [12].

The paper outcomes also demonstrate that non-green goods generate a significantly negative association with material footprint for the BRICS context. This indicates that goods which are not considered environmentally friendly have a significant negative impact on the material footprint of the BRICS countries. Additionally, the findings of the paper indicate that, in the context of the BRICS nations, non-green products have a significant adverse effect on the material footprint. This finding suggests that these products which fail to meet environmental standards have a substantial adverse impact on the material footprint of the BRICS nations. This means that the production and use of these non-green products consume substantial amounts of resources and frequently result in waste and pollution. Therefore, within the context of the BRICS group, non-green products have a negative association with material footprint for a variety of reasons. To begin with, the manufacturing process frequently necessitates the extraction and subsequent refining of basic materials, actions that can exert a substantial influence on the environment. As an illustration, the extraction of metals and minerals may result in the devastation of habitats, water bodies, and deforestation [40]. Second, the transportation of non-green products frequently involves the emission of greenhouse gases and contribution to climate change through the use of fossil fuels. Additionally, waste production is a frequent consequence of non-green product consumption, leading to the contamination of water and land resources [41].

Table 7. FGLS and PCSE results. The dependent factor is LogMAFT.

Variables	FGLS	PCSE
LogECO	0.0668 *** (0.0120)	0.1151 *** (0.0180)
LogRDN	−0.4306 *** (0.0271)	−0.3387 *** (0.0412)
LogGD	0.5974 *** (0.0288)	0.468245 *** (0.0443)
LogY	0.00007 (0.0028)	0.0080416 (0.0065)
LogESTR	0.1309 *** (0.0168133)	0.0367 (0.0335)
Constant	0.0512 (0.209)	0.0687 (0.3472)
Observations	100	100
R-squared	-	0.8857

Notes: *** indicate that the coefficients are significant at the 1% level of significance. Standard errors in parentheses.

This research proves that green goods produce a significant and positive connection with material footprint. As the BRICS countries demonstrate, this implies that the production and consumption of green products may result in an increase in the material footprint of a product. One instance of a necessity for the manufacturing of electric vehicles is a substantial quantity of lithium, an environmentally precarious rare earth metal [42]. Furthermore, it should be noted that the transportation, along with innovation, of environmentally friendly products can occasionally require more resources than the transportation and innovation of conventional products, which causes suppliers to introduce them only when they are profitable. This is due to the fact that green products are frequently transported over shorter distances in order to maintain their freshness or because they are composed of locally sourced materials [7,8].

Environmental governance, in this paper, generates a positive and significant association with material footprint in the BRICS economies. This discovery indicates that the implementation of efficient environmental policies and regulations is resulting in a rise in the material footprint within these nations. On that note, effective environmental governance may be influencing the BRICS nations to increase their production of environmentally responsible products and services, putting considerable pressure on existing resources. For instance, stricter regulations pertaining to air and water pollution could spur the creation of innovative emission-reducing technologies [4] but at a high resource cost. Government subsidies for renewable energy may also serve as an incentive for the development and installation of wind turbines and solar panels, but these new technologies may also require more resources to produce and operate. Another context is that labelling regulations for food items may influence consumers to purchase more sustainable alternatives since it educates them about the ecological consequences of their food selections [14]. This eventually, can lead to an increase in the production of these products, which may require more resources. Moreover, the deployment of government subsidies to encourage the acquisition of electric vehicles may stimulate their demand [9], yet a large number of resources are required in the production and consumption stages.

Economic growth depicts an insignificant and positive relationship with material footprint in this study. Thus, the association between material footprint and economic development in the BRICS nations should be elucidated through various lenses. One potential possibility is that individuals' increased consumption of products and services necessitates more resources for production and consumption as their wealth increases [43]. Moreover, resource extraction and refining may increase as economies industrialize in tandem with their expansion [44].

This section provides an more outline of the empirical results obtained from the research. The empirical outcomes of the FGLS regression with green investments as the dependent variable are shown in Table 8. The purpose of the PCSE results is solely to verify robustness.

Table 8. FGLS and PCSE results. The dependent factor is LogGEN.

Variables	FGLS	PCSE
LogECO	0.0132 *** (0.0043)	−0.2975 *** (0.0853)
LogRDN	−0.1225 *** (0.0103)	−0.3574 *** (0.1328)
LogGD	−0.1433 *** (0.0097)	0.5227 *** (0.1797)
LogY	0.0000822 (0.0021)	0.0991 * (0.0544)
LogESTR	0.0234 ** (0.0118)	0.1091 (0.1243)
Constant	2.8338 *** (0.0691)	−0.7329 (1.5276)
Observations	100	100
R-squared	-	0.2206

Notes: ***, **, and * indicate that the coefficients are significant at the 1%, 5%, and 10% level of significance, respectively. Standard errors in parentheses.

Firstly, the results demonstrates that eco-innovation has a significantly positive relationship with renewable energy. Consequently, with the progression of eco-innovation, the probability of improved utilization of renewable energy within the BRICS nations increases. Hence, numerous factors can account for this outcome. To begin with, it is possible that eco-innovation is propelling the advancement of renewable energy technologies that are more cost-effective and efficient [45], thereby increasing their competitiveness vis-à-vis conventional fossil fuels in these nations. Furthermore, eco-innovation is facilitating improvements in the operational efficiency of renewable energy systems [46] within the BRICS nations. These enhancements include heightened energy output, diminished energy losses, decreased costs, and enhanced dependability. Furthermore, the promotion of eco-innovation-driven sustainability objectives could be encouraging a shift from fossil fuels to renewable energy sources [47], which are regarded as being more ecologically sustainable in these nations.

This research also provides evidence that non-green goods generate a negative and significant relationship with renewable energy use. This suggests that the BRICS group's adoption of renewable energy is declining in tandem with rising consumption of non-green products. There are several explanations for this association. Production of non-green commodities frequently requires large quantities of energy, mostly from fossil fuels [48] in the BRICS nations. This dependence on fossil fuels hinders the switch to renewable energy sources by increasing greenhouse gas emissions and environmental damage. Second, we may draw attention to the fact that non-green products frequently harm the environment as a result of their manufacturing processes, the creation of waste, or the disposal techniques they employ [49]. The BRICS countries' aspirations for sustainability and the deployment of renewable energy are at odds with this environmental harm. Third, when buying non-green products, customers may be putting price and convenience ahead of environmental concerns [50] with respect to the BRICS nations. Therefore, the dearth of interest in eco-friendly items may deter investors from making renewable energy investments. Lastly, some companies, particularly state-owned businesses in the BRICS nations that rely largely on fossil fuels for the manufacture of non-green commodities, may oppose the switch to renewable energy out of concern for lost jobs or decreased profitability [51]. Thus, technologies for renewable energy may take longer to adapt as a result of this reluctance.

In this study, green goods indicate a significantly negative relationship with renewable energy consumption in the BRICS situation. This implies that an increase in the consumption of environmentally friendly products is associated with a decline in the adoption of renewable energy. There are multiple potential factors that could explain this link. First of all, green products are frequently made with increased energy efficiency in mind, which lowers total energy usage [10]. Hence, an impression that there is less of a need for renewable energy sources in the BRICS nations may result from this decline in energy consumption. Secondly, certain businesses could partake in greenwashing, which involves inflating the ecological advantages of their merchandise to draw in customers [11]. This may provide the erroneous impression that, even in the BRICS nations, environmentally friendly products are more sustainable by nature, especially in cases when their energy sources or production methods are not eco-friendly. Lastly, we may argue that the BRICS group's renewable energy infrastructure is either undeveloped or unable to fulfil the whole demand for environmentally friendly products [52]. This may cause people to become more dependent on conventional energy sources, even when producing and using environmentally beneficial goods.

This paper also discloses that environmental governance illustrates a positive and significant association with green energy use. This implies that with the reinforcement of environmental governance frameworks, there is a propensity for the implementation of renewable energy sources such as hydroelectric, solar, wind, biomass, and geothermal. This positive association can be attributed to various factors. In order to promote the switch from fossil fuels to greener renewable energy sources, the BRICS nations may be including regulatory frameworks that set explicit guidelines and standards for energy production and use [53]. In a similar spirit, legislative incentives such as tax exemptions, financial support, and subsidies for renewable energy technologies increase their attractiveness and competitiveness to businesses in the BRICS region [54]. A consequence of the strong environmental governance of the BRICS nations might also be that it guarantees the application and enforcement of environmental laws, levelling the playing field for the renewable energy sectors [13].

Economic growth, in this research, shows an insignificantly positive association with green energy consumption. This implies that there is no discernible or consistent rise in the adoption of renewable energy as the economy expands; this asymmetrical connection can be ascribed to a number of factors. For instance, during times of economic expansion, the governments and corporations of the BRICS nations may place a higher priority on short-term financial benefits than long-term environmental sustainability, which would result in a continuous reliance on fossil fuels for the generation of energy [55]. It is difficult to redirect resources and expertise toward renewable energy sources in the BRICS nations due to past investments in fossil fuel infrastructure and technology that have created a path dependence [56]. Furthermore, even in times of economic expansion, some BRICS companies and governments may view renewable energy as more costly or less dependable than conventional fossil fuels, which would impede their adoption [54]. The next section presents causality tests findings.

The preceding identification of significant statistical relationships in Tables 7 and 8 does not inherently establish a causal relationship between the variables. We used the [32] method to address this. Table 9 displays the results of the Granger causality analysis.

The test revealed bi-directional causality association between non-green goods and material footprint, green goods and material footprint, renewable energy use and eco-innovation, renewable energy consumption and environmental governance, and renewable energy use and green goods. Furthermore, the tests also illustrate a uni-directional causality relationship running from eco-innovation to material footprint, environmental governance to material footprint, non-green goods to renewable energy consumption, material footprint to economic development, and renewable energy consumption to economic growth. As such, the conclusions of these causality analyses have important policy ramifications which are discussed in the following section.

Table 9. Causality tests results.

Null Hypothesis	Statistic	Prob	Lag	Causality Flow
LogMAFT does not homogenously cause LogECO	0.0216	0.5173	1	LogECO → LogMAFT
LogECO does not homogenously cause LogMAFT	2.2971 **	0.0216	1	
LogMAFT does not homogenously cause LogRDN	1.8304 *	0.0672	1	LogRDN ↔ LogMAFT
LogRDN does not homogenously cause LogMAFT	4.2763 ***	0.000	1	
LogMAFT does not homogenously cause LogESTR	2.0064 **	0.0448	1	LogESTR → LogMAFT
LogESTR does not homogenously cause LogMAFT	0.5267	0.5984	1	
LogMAFT does not homogenously cause LogGD	2.8248 ***	0.0047	1	LogGD ↔ LogMAFT
LogGD does not homogenously cause LogMAFT	3.4893 ***	0.0005	1	
LogMAFT does not homogenously cause LogY	2.6274 ***	0.0086	1	LogMAFT → LogY
LogY does not homogenously cause LogMAFT	0.1798	0.8573	1	
LogGEN does not homogenously cause LogECO	2.3572 **	0.0184	1	LogGEN ↔ LogECO
LogECO does not homogenously cause LogGEN	3.7630 ***	0.0002	1	
LogGEN does not homogenously cause LogRDN	0.8839	0.3768	1	LogRDN → LogGEN
LogRDN does not homogenously cause LogGEN	3.9636 ***	0.0001	1	
LogGEN does not homogenously cause LogESTR	3.0147 ***	0.0026	1	LogGEN ↔ LogESTR
LogESTR does not homogenously cause LogGEN	4.0510 ***	0.0001	1	
LogGEN does not homogenously cause LogGD	2.0702 **	0.0384	1	LogGEN ↔ LogGD
LogGD does not homogenously cause LogGEN	5.7166 ***	0.0000	1	
LogGEN does not homogenously cause LogY	3.1035 ***	0.0019	1	LogGEN → LogY
LogY does not homogenously cause LogGEN	0.9701	0.3320	1	

Notes: ***, **, and * illustrates that the coefficients are significant at the 1%, 5% and 10% level of significance, respectively.

5. Policy Implications

The study reveals that eco-innovation proves a statistically significant positive relationship with both material footprint and renewable energy consumption. Moreover, this research finds bi-directional causality involving renewable energy use and eco-innovation, and uni-directional causality association from eco-innovation to material footprint. Hence, in the context of the BRICS group, eco-innovation should not be regarded as a panacea for environmental sustainability; although it can enhance resource efficiency, it might not be adequate to completely isolate material footprint expansion from economic expansion. Therefore, to attain a truly sustainable future, additional policies are required, such as resource conservation measures, the adoption of green energy sources, and the encouragement of sustainable consumption. Furthermore, in the BRICS nations, eco-innovation needs to be well-targeted to optimize its environmental advantages. Thus, even if they do not immediately support economic expansion, eco-innovation initiatives ought to concentrate on methods and technologies that result in the largest reductions in material footprint. Vigorous monitoring and assessment within the BRICS group is also necessary to foster eco-innovation. Therefore, it is essential to regularly evaluate the efficacy of eco-innovation policies in order to pinpoint areas in need of development and confirm that these policies are accomplishing the desired environmental goals.

The paper outcomes also demonstrate that non-green goods generate a significantly negative association with both material footprint and renewable energy use for the BRICS context. Moreover, non-green goods demonstrate feedback causality with material footprint, and a one-way causality exists from non-green goods to renewable energy consumption. As a result, with a view to reducing the amounts of resources consumed and waste produced by non-green products, the BRICS countries should adopt and enforce mandatory eco-design standards. Extended producer responsibility programs are also necessary so as to hold manufacturers responsible for the management of their products' end-of-life. In the same line, policymakers can promote circular economy techniques, such as recycling, reuse, and remanufacturing, to lower the overall material demand for non-green goods production. As a means to educate customers on the environmental impact and material footprint of non-green items, the BRICS countries should also mandate strict environmental labelling programs. These actions raise consumer awareness of how non-green products affect the environment and encourage the use of sustainable alternatives. It is also important to have policies in place to deter the manufacture and consumption of non-green products. These could take the form of taxes, subsidies, or laws that make non-green products less appealing to producers and consumers.

This research proves that green goods produce a significant and positive connection with material footprint, but exhibit a significantly negative relationship with renewable energy consumption in the BRICS situation. Furthermore, this paper reports a two-way causality between green goods and material footprint, along with renewable energy use and green goods. These findings have important policy implications for the BRICS countries. A more nuanced approach to environmentally friendly products is therefore required within the BRICS nations. Although environmentally friendly products are often thought to be superior to non-green products, this research implies that not all green products are made equally. Therefore, when it comes to promoting green products, authorities should be more selective and concentrate on those that have the biggest positive effects on the environment. It is also advisable to measure the environmental impact of green goods using life cycle assessment, or LCA. According to [57], LCA is a technique for evaluating a product's environmental impact at every stage of its life cycle, from the extraction of raw materials to disposal. For the purpose of reducing the environmental impact of producing green goods, BRICS policymakers should use life cycle assessment (LCA) to identify and promote those that have a lower total environmental impact. This will also stimulate the adoption of sustainable materials and sourcing procedures.

Furthermore, the operational efficiency of the renewable energy system will be accurately determined by employing key performance indicators within the BRICS community. The emphasis should be placed on one of the most valuable assets, that is communities, in order to achieve advancement and success, i.e., maintain the community's awareness, engage the community's participation, sustain the community's curiosity, and also foster the community's motivation. The policymakers must work diligently to achieve four key performance indicators for human capital. This is a potent management tool that leads to exceptional outcomes as policymakers gain certain managerial abilities such as problem-solving, decision-making, networking, resilience, entrepreneurial mindset, strategic thinking, flexibility, and adaptability.

Environmental governance, in this paper, generates a positive and significant association with material footprint and also green energy use in the BRICS economies. This paper also finds the presence of a reciprocal causality between environmental governance and renewable energy use, and a non-reciprocal causality from environmental governance to material footprint is also validated. Given the circumstances, it is critical to reassess and enhance the frameworks of environmental governance within the BRICS nations. In light of this, it is imperative to conduct a comprehensive analysis of current environmental policies and regulations in order to pinpoint any instances in which they might be facilitating rising material use. This can be implementing more flexible and performance-based standards, simplifying regulatory procedures, or investigating different policy strategies that emphasize resource efficiency and green economy ideas. In order to lessen their material imprint, BRICS decision-makers should also push companies to use eco-innovative technologies, sustainable production techniques, and circular economy ideas. This could entail encouraging resource-efficient behaviours, supporting the use of clean technologies, and offering incentives for green research and development. It is imperative to consistently observe and assess the efficacy of environmental governance initiatives within the framework of the BRICS nations. This is essential for determining how environmental laws and regulations affect material footprint. Afterwards, we can utilize these data to improve current green laws and regulations, create fresh green approaches, and adjust to evolving environmental issues.

This research also posits that economic growth creates an insignificant and positive relationship with material footprint and also green energy consumption. As well the paper outlines a uni-directional causality relationship running from both material footprint and green energy use to economic development is confirmed. Given the aforementioned, it is recommended that the BRICS group make investments in environmentally sustainable technologies and infrastructure. These investments can encourage the creation of a more sustainable future by lessening the negative effects of economic activity on the environment. These nations should also increase global collaboration on environmental issues. Thus, agreements to lower greenhouse gas emissions, safeguard common habitats, and advance sustainable trade practices might all be a part of international cooperation to address environmental issues that cut across state boundaries. In a same spirit, the BRICS nations must prioritize educating the public and encouraging environmental responsibility. In this sense, community-based projects, public education campaigns, and support for environmental interest groups might all be used to inform the public about the value of environmental conservation and motivate people to take action to lessen their impact on the environment.

6. Conclusions

In a multivariate model utilizing annual panel data from 2000 to 2019, the current study seeks to investigate the factors that have a relationship and impact trade-adjusted material footprint and green energy use across all BRICS nations. This study examines the association and impact of environmental governance, green goods, non-green goods, eco-innovation, and economic growth on material footprint and renewable energy use. To achieve a comprehensive and rigorous analysis, we utilize various econometric methodologies. In order to analyse the cross-sectional dependence (CSD) in our panel data, we utilize the second-generation unit root tests (CADF and CIPS tests). Additionally, we implement the Pedroni and Kao panel cointegration technique to investigate long-term relationships. The panel feasible generalized least squares (FGLS) and panel corrected standard errors (PCSE) procedures are employed to examine the relationships between the variables. Subsequently, a panel causality test with a heterogeneous nature is performed in order to ascertain causality between the variables.

The findings of the study demonstrate a statistically significant positive association between eco-innovation and both material footprint and renewable energy consumption. Furthermore, this study reveals a reciprocal causality relationship between the utilization of renewable energy and eco-innovation. Additionally, it identifies a unidirectional causality where eco-innovation influences the material footprint. The outcomes of the research also indicate that non-environmentally friendly products have a significant adverse link with both material footprint and the consumption of renewable energy within the BRICS setting. Furthermore, it can be observed that there is a reciprocal causality relationship between non-green goods and their material footprint, indicating a feedback loop. Additionally, there is a one-way causality relationship from non-green goods to the consumption of renewable energy.

Moreover, this study provides evidence that green products exhibit a significantly positive association with material footprint, while demonstrating a significantly adverse association with renewable energy use within the context of the BRICS nations. Moreover, this study presents findings that indicate a two-way causality between environmentally friendly products and material footprint, along with renewable energy use and green goods. In addition, environmental governance reveals a positively significant connection with two environmental metrics (material footprint and green energy use). We also find the presence of a reciprocal causality between environmental governance and renewable energy consumption, and a non-reciprocal causality from environmental governance to material footprint is also supported. This research also posits that economic growth creates an insignificant and positive relationship with material footprint and also green energy consumption. As well the paper outlines a uni-directional causality relationship running from both material footprint and green energy use to economic development is confirmed.

Hence, it is recommended that future research endeavours should explore the possibility of extending the analysis to incorporate additional developing countries or regions outside of the BRICS nations. This would enable a more holistic comprehension of the interconnections among environmental governance, green goods, non-green goods, eco-innovation, renewable energy, and material footprint within diverse contexts. Similarly, it is crucial to disaggregate the data into more smaller segments, such as distinct industries or product classifications, in order to discern intricate associations among variables and acquire a more profound comprehension of the fundamental mechanisms in operation. Furthermore, it is crucial to integrate quantitative analysis with qualitative methodologies, including case studies, interviews, or surveys, so as to acquire comprehensive insights into the decision-making procedures and motivations of businesses, policymakers, and consumers. Such an approach would facilitate a more comprehensive comprehension of the various factors that influence the adoption of renewable energy and the reduction in material footprint.

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