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Prospect of Trade and Innovation in Renewable Energy Deployment: A Comparative analysis between BRICS and MINT Countries

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Abstract

The current study thus explored the impact of technological innovation and trade openness on clean energy while accounting for economic growth, access to electricity, pollution, industrial restructuring, and urbanization using data from 1990 to 2020 for both the MINT and BRICS economies. A series of test were performed for a robust analysis using second generation econometrics approaches before proceeding to investigate the long-run linkages between renewable energy and the duo of innovation and trade using the Prais-Winsten regression model with panel-corrected standard errors (PCSE) while the Driscoll-Kraay standard errors test was applied for robustness checks. The results, firstly confirm the presence of heterogeneity, cross-sectional dependence, and cointegration among the selected variables. Secondly, technological innovation as a renewable energy determinant demonstrated negative elasticities in both BRICS countries and the full sample, but a positive elasticity in the MINT countries. Thirdly, concerning trade liberalisation, negative elasticities were obtained for the full sample and MINT countries, while the elasticities were positive for the BRICS bloc. Fourthly, the roles of economic growth and environmental pollution reveal a negative impact on renewable energy consumption for all samples while urbanisation and industrial restructuring promote renewable energy developments only in the BRICS bloc. Policy implications are discussed.

Keywords: Renewable energy, trade liberalization, technological innovation, Prais-Winsten regression

1. Introduction

Amidst the Covid-19 threat, there remains an old-time problem with climate change and its dire effects on ecological health. Humanity has been engulfed in difficulties concerning environmental change, which perhaps is the greatest threat to the future generations that requires adequate attention within a minimal time (Li & Haneklaus, 2022; Lin et al. 2022). This regurgitates the growing need for energy transition and new technology. To meet international energy and climate targets, an extensive global effort to develop and deploy clean energy technology is urgently needed to cut carbon emissions. Despite the challenges posed by the Covid-19 situation, several recent achievements offer us reason to be optimistic about the world's potential to speed sustainable energy transitions through renewable energy technological innovations to meet global environmental and climate goals (Andrijevic et al., 2020; Asongu & Odhiambo, 2020; Pathak et al., 2022; Gyamfi et al. 2022). As such, various developments about the state of renewable energy (RE) technologies and its utilization have been noted to be critical for attaining economic growth and sustainable development goals (SDGs)(Khan et al., 2022; Chen et al., 2021; Asongu & Odhiambo, 2021; Erdoğan et al., 2021; Edziah et al., 2022; Liu et al., 2023).

Renewable energy expansion could also help advance many other goals. According to a study conducted by the International Council of Science (ICSU, 2017), the establishment of universal energy access and the growth of renewable energy are expected to have a major positive influence on SDGs. Essentially, renewable energy development is critical for achieving carbon neutrality and overcoming today's energy dilemma and Vidinopoulos et al. (2020) have noted that accelerating the use of renewable energy has become an important path toward carbon neutrality. However, despite the tremendous advances led by global energy transition efforts, the disparity in renewable technology innovation has been identified as worrying for the early industrial revolution (Lin & Chen, 2019; Nicolli & Vona, 2016; Fotio et al., 2022; Dimnwobi et al., 2022). Meanwhile, the use of renewable energy can be promoted in a variety of ways as supported by many past studies (Amri, 2019; Ben Aïssa et al., 2014; Wang & Lee, 2022). For instance, through multiple factors including economic growth (Gyimah et al., 2022; Duran et al., 2022), technology innovation (Zhao et al., 2022; Bekun et al. 2022), labor (Ziaei, 2022), capital (Shidong et al., 2022; Gyamfi et al. 2021), population(Yang et al., 2022; Alola et al. 2021), urbanization (Shahbaz et al., 2022; Erdoğan et al., 2022), carbon emissions (Murshed et al., 2022; Gyamfi et al. 2021), and electric power consumption (He et al., 2021), affect renewable energy consumption.

To increase the usage of renewable energy, an integrated package of actions and regulations must be implemented in accordance with national needs and priorities. In this regard, a comprehensive policy planning centred on technology and trade openness is required to lead the energy infrastructure toward sustainability. Besides, legislation, plan adoption techniques, action programs, and incentive policies can altogether pave way for more remarkable technical advancement and cheaper prices in terms of stimulating a higher level of renewable energy usage. Trade openness is becoming an important emerging macroeconomic determinant in global energy usage, especially for renewable energy consumption level. Usman and Makhdum (2021), argued that technological innovation is the key driver of renewable adoption and went further to posit that technological advancement is the best barometer for preventing environmental damage. Also, it is widely understood that the usage of renewable energy is contingent upon technological transfer, which is inextricably tied to international trade as noted by Ben Aïssa et al. (2014). As such, promoting technological innovation has become a widely accepted strategy for addressing environmental issues such as CO_2 emissions among other greenhouse gas (GHG) emission. In fact, Cheng et al. (2021) discovered that renewable energy policies in countries with liberalized energy markets are more successful in supporting green innovation.

Currently, the global energy industry is experiencing an accelerating transformation at an astounding level (Yuan et al., 2022). There are a variety of factors contributing to this fast change among which the need to combat climate change stands out. Meanwhile, politicians and governments are also confronted with additional concerns such as maintaining a cheap energy supply, energy security, and improving energy accessibility for everyone (Asongu et al., 2019; Bhattarai et al., 2022; Chanchangi et al., 2022; Onifade, 2022; Ciaccia, 2022). Therefore, increased regulations, treaties and climate change advocacy are all putting more pressure on governments to promote the use of renewable energy across the globe (Uzar, 2020). This development has thus increased researchers' interest in understanding renewable energy determinants. Among other factors, a number of empirical studies have been carried out to look into the relationship between renewable energy growth from the trade and innovations perspectives.

Looking at the link between trade and renewable energy first, a copious of research examined the connection between these variables, but often, trade is not viewed as an independent variable but rather as a control variable or threshold factor. Trade openness is generally seen as a crucial tool for economic success as it generally allows for the growth of domestic markets via export expansion (Lane & Pretes, 2020; Khatir et al. 2022; Yussif et al. 2022). But in recent times, the benefits have expanded further to cover environmental issues as it boosts the acquisition of energy-efficient technologies from abroad especially when there are strong bilateral trade relations among countries.

Some studies have found that trade is a primary driver of per capita renewable energy usage. For example, Qamruzzaman and Jianguo (2020) observed that international commerce has a favourable effect on the demand for renewable sources in low-, middle-and high-income nations. Ben Aïssa et al. (2014) used data from 11 African countries between 1980 and 2008 to study the link between GDP, trade, and renewable energy utilisation. The long-run analysis they conducted showed bidirectional correlations between GDP and trade factors, as well as a one-way association regarding clean energy, trade, and GDP. In the short term, their findings support the bidirectional relationship between trade and GDP while rejecting the idea of a linkage between GDP and renewable energy, and trade and renewable energy. Alam and Murad (2020) evaluated the influence of economic development, trade openness, and technology progress on renewable energy in 25 Organization for Economic Cooperation and Development (OECD) nations. The empirical findings revealed that trade openness and technology advancement had a significant positive impact on OECD nations' adoption of long-term renewable energy.

On the aspect of the link between technology innovation and renewable energy, some studies have been conducted in the literature. Considering the advancements in sciences that have culminated in various contributions to humanity, government officials and think tanks around the world have increasingly recognized the relevance of innovations in addressing climate targets especially in the areas of reducing GHGs like CO_2 emissions (Guo et al., 2017). As noted by Alola and Onifade (2022), technological innovation in various energy sources can yield environmental benefits. Their assertions and conclusions were driven by their study of how innovation creates a pathway to carbon neutrality in the case of the Finnish economy. However, the link between renewable energy policies and innovation is arguably a newer topic of interest in the growing literature. In practice, the primary goal of RE policies is to produce a particular amount of clean energy demand (Johnstone et al., 2012). According to an empirical study, renewable energy consumption has a cointegration relationship with technological innovation and other external variables (Ji, 2016). This indicates that the stimulating impact of technological innovation on renewable energy output takes time to emerge. Also, in a study by Sohag et al. (2015), an ARDL testing technique was used to examine the impacts of technical advancement on energy intake in Malaysia. They discovered that technological innovation might assist in minimizing energy use by enhancing energy efficiency. Additionally, technological advancements can cushion climate change by introducing energy-efficient equipment and energy advances as concluded in the studies of Shahbaz et al. (2020) and Sharif et al. (2020).

Overall, while technological innovation and trade openness may be mitigation factors for reducing environmental pollution through the promotion of renewables as most of the highlighted studies in previous paragraphs point to their beneficial sides, no specific study has been conducted to understand the role of technological innovation and trade openness on clean energy in the MINT and BRICS countries while accounting for economic growth, access to electricity, pollution, industrial restructuring, and urbanization. Meanwhile a recommendation of empirical-based policies will not be only beneficial for these economic blocs alone but for the global drive for environmental sustainability as these two blocs account for more than half of the entire global GHGs emissions (UNEP, 2021). Moreover, failure to address the underlying concerns of global carbon emission is disastrous for the environment in the medium and long terms (IPCC (2007). Therefore, the current study contributes to the literature by addressing the unanswered questions concerning the prospects of trade policy and technological innovation in renewable energy adoption and utilization in these two major economic blocs that account for a substantial share of the global energy demand (BP, 2021).

Furthermore, another important gap in the literature is that most studies on renewable energy primarily focus on demand perspectives (Samant et al., 2020; Tsoutsos & Stamboulis, 2005); and what impact it has on the debate on environmental dilapidation to the exclusion of the supply debate on how renewables can be deployed as an alternative to fossil energy (Elliott, 2015; Madlener & Stagl, 2005). Until now, no analysis has been shown to ascertain from a comparative perspective the possible effects of trade and technology innovation on renewable deployment in the BRICS and MINT countries. These apparent gaps motivate the focus of the present study. The theoretical underpinnings motivating the study are consistent with the theoretical framework for halo and haven pollution hypotheses. Accordingly, the theoretical haven theoretical framework is consistent on the position that trade will expose domestic economies to higher levels of pollution and less renewable sources of energy while according to the theoretical halo perspective, innovation partly resulting from globalisation-driven competition will induce domestic economies to reduce their greenhouse gas emissions levels and by extension, improve their renewable sources of energy owing to technological innovations that are environmentally friendly (Nguyen-Thanh et al., 2022). The rest of the study is structured as follows. Section 2 discusses the methodology and materials, while the results are presented and discussed in section 3. The study then concludes by providing policy approaches to be adopted towards promoting sustainable development and clean energy transition in section 4.

2. Materials and Methods

2.1 Data

The study aims at investigating the impact of technological innovation and trade liberalisation on renewable energy consumption in BRICS and MINT countries. However, to avoid the possible biases that may arise from variable omission; the study incorporates a number of control variables. To this end, the utilized data on MINT and BRICS countries covers the period from 1990 to 2020. The data are sourced from the World Bank Development Indicators (WDI, 2021) database and the full meaning of the countries included in the MINT and the BRICS blocs have been provided in the list of nomenclature. The availability of data on the variables from the World Bank is updated up until 2020 for majority of the variables. Hence, the current study's sample framework span from 1990 to 2020. The summary of the selected variables, the proxies used to represent them, the unit of these variables in terms of measurement, and their sources are shown in Table 1. The choice of MINT and BRICS countries is justified in the next section. All factors are log converted to allow for the interpretation of the estimated coefficients as elasticities.

2.1.1 Dependent Variables

This study aims at understanding what variables promote renewable energy consumption or otherwise. Hence renewable energy consumption was the targeted dependent variable in the baseline model for the analysis as seen in Equation (1). The study thus utilizes the data from BRICS and MINT economic blocs for the empirical analysis. Alliances like BRICS (Brazil, Russia, India, China, and South Africa) may be tremendously beneficial if they invest in clean energy and use their combined might to advocate for stricter, legally enforceable protocols on national and worldwide bases. The BRICS bloc's investment in renewable energy has nearly tripled in the last decade (Kamat, 2020) and this study seeks to understand in part, the likely factors that have led to this development. While conducting this analysis, the study also creates a comparative analysis with the MINT countries. Most of the countries in these two blocs, apart from being among the fastest emerging economies also share some factors in common like being some of the leading pollutant emitting nations with growing environmental degradation. As such, Akram et al. (2022) noted that the MINT nations (Mexico, Indonesia, Nigeria, and Turkey) should be given special consideration as far as the issues of reducing global carbon emissions are concerned.

2.1.2. Independent Variables

The current study assesses two variables as the major independent variables vis-à-vis the study's outlined aims and objectives, namely trade openness and technology innovation.

1. ***Technology innovation***: The modern industrial period has transformed into a quickly evolving society that relies heavily on technical breakthroughs to survive. However, this technology has provided contradicting results on its role in renewable energy use and consequently on environmental quality as noted by Suki et al. (2022). Even the study by Álvarez-Herránz et al. (2017) also revealed an insignificant relationship between innovation and environmental deterioration. The current study thus hypothesises that $\boldsymbol{H_0}$: technological innovation increases renewable energy advancement and reduces carbon emissions against the alternative that postulates the contrary view. The study utilises patent information as a proxy for technological innovation as proposed by Lin and Zhu (2019) and Onifade and Alola (2022).
2. ***Trade openness***: Trade globalization has resulted in significant changes in energy use in several nations (Baek et al., 2009). Some economists have also argued passionately over the environmental repercussions of trade liberalization (Khan et al., 2022; Li et al., 2022). However, the importance of trading in energy consumption, particularly renewable energy, remains a controversial matter (Ali et al., 2021; Khan et al., 2022). In the current study, trade as a percentage of gross domestic product was utilised for the purpose of the empirical analysis in the light of highlighted extant studies.

2.1.3. Control Variables

1. Economic Growth: Some studies have debated the correlation between renewable energy and economic advancement (Apergis & Payne, 2010; Balcilar et al., 2018; Koçak & Şarkgüneşi, 2017; Ozcan & Ozturk, 2019). Most of these studies show that growth is an imperative factor to be considered when assessing the level of progress in renewable energy consumption. Hence, it is prudent to control for this factor when finding alternative resources for environmental quality improvement.
2. Access to energy: Countries that ratified the SDGs commit to achieving cheap and clean energy access by 2030 (Alem & Demeke, 2020). It becomes necessary to add to the energy mix to reach an inclusive number of people that are having access to energy. Rabah (2005) contends that the demand for primary energy, whether renewable or non-renewable, is mainly driven by low electrification rates and availability of energy.
3. Environmental degradation and Pollution: Carbon emissions are routinely incorporated in models to include the impact of climate change or environmental degradation. Zhang et al. (2021) and Sadorsky (2009) have shown that the environmental danger posed by high greenhouse gas intensity leads to an increase in renewable energy usage. Hence, carbon emission per capita was used to proxy for environmental degradation.
4. Urbanization: Many researchers have found evidence of urbanization's harmful impacts on the environment (Liu & Bae, 2018;Wang et al., 2018). However, some works have also provided a framework that represents the prospect of urbanization leading to a rise in the intake of green energy (Shahbaz et al., 2022). In this analysis, urbanization is measured by the fraction of urban residents in the overall population.
5. Industrial Restructuring: An evolving economy can increase the use of energy or otherwise (Miao et al., 2022) and industrialization can be a significant source of pollution and environmental deterioration. Thus, restructuring of industrial arrangements and activities beyond business as usual may promote environmental quality. It has been observed that restructuring is an effective means of achieving green and sustainable development and some studies have argued that service is the best proxy for measuring industrial change as done in this study (Xin-gang & Jin, 2022; Zhou & Li, 2020).

2.2. Model Specification and Estimation Approach

As already mentioned, the aim of the study is to investigate the impact of technology innovation and trade liberalisation on renewable energy development as such, the functional form of this interplay among the variables is provided in equation (1) which represents the first phase of the study's estimations (Model 1). However, given that renewable energy can potentially generate environmental externalities, the study also explores these possible externalities by incorporating environmental pollution as dependent variable in a second estimation (Model 2) following the functional form of the interplay among variables as seen in Equation (2).

$$lnRen_{it} = f(lnti_{it}, lntr_{it}, lny_{it}, lnate_{it}, lnCO_{2it}, lnur_{it}, lnser_{it}) \quad (1)$$

$$lnCO_{2it} = f(lnRen_{it}, lnti_{it}, lntr_{it}, lny_{it}, lnate_{it}, lnur_{it}, lnser_{it}) \quad (2)$$

In both Equation 1 and Equation 2, all variables have been appropriately defined as shown in Table 1 for country i in period t. A series of statistical tests were conducted before assessing the long-run estimates for the models. The outcomes of these tests have been detailed out in the discussion section.

The study employs the Prais-Winsten regression model with panel-corrected standard errors (PCSE) and the Driscoll-Kraay standard errors for robustness checks. The PCSE was first proposed by (BECK & Katz, 1995) to address estimation weaknesses of the generalized least squares in analysing time-series cross-sectional data.

This approach carries special advantages that make the choice of the method beneficial for the current study. Specifically, the PCSE solves the issues of cross-sectional dependence that has been identified as a major challenge in panel data analysis (Bekun et al., 2021; Caglar et al., 2022; Appiah et al., 2022). Furthermore, the approach also jointly addresses the concerns of autocorrelation and heteroskedasticity in time-series cross-sectional (TSCS) data as pointed out in other empirical studies (Kongkuah et al., 2021; Sharmin et al., 2022).

3. Results and Discussions

As already indicated, the present study employed data spanning 1990 to 2020 for the BRICS and the MINT economies with the original data sourced from the WDI database. Table 2 presents the summary of the variables for a full sample, for the BRICS sample, and then for the MINT countries. All variables are converted into log form. Results for the full sample reveal that industrial construction has an average value of 26.72 at constant 2015 US$ with a standard deviation of 0.98 which is quite large compared with economic growth (average = 8.31, standard deviation= 0.80) and technology innovation (average = 7.86, standard deviation =

2.20). Also, access to electricity shows an average of 4.41 with a standard deviation of 0.28, while trade liberalization has the average of 3.72 with a standard deviation of 0.36. For renewable energy, the average is 3.09 with a standard deviation of 0.94 while urbanisation's average is 0.79 with standard deviation of 0.81. Table 3 further reveals marginal differences in the average values for both BRICS and MINT countries. More specifically, whereas the average values for renewable energy, trade liberalisation, economic growth, and urbanisation are marginally high for MINT countries than BRICS countries, the opposite is the case when technology innovation, access to electricity, environmental pollution, and industrial reconstruction are considered.

The study proceeded to perform a correlation analysis to ascertain the strength of the statistical nexuses among the variables. The result from the pairwise correlation analysis is presented in Table 3a, and a quick glance through the table reveals that while some variables exhibit a positive relationship, others display negative nexuses. A positive relationship indicates that the variables may positively influence the dependent variable and vice versa. The results show the absence of possible multicollinearity among variables given that none of the correlation coefficients exceeded 0.75 (Sun et al., 2020).

3.1. Slope Homogeneity Test Results

The current study performed the slope Pesaran–Yamagata homogeneity test to determine whether there is slope homogeneity. From the result presented in Table 3b, we fail to reject the alternate hypothesis of heterogeneity at a 1% significance level. This implies the presence of heterogeneity involving the factors across the panels. This result thus gives credence to employ panel estimators that are robust to heterogeneity across various cross-sections in a panel to produce robust outcomes as reported in Table 3b.

3.2. Cross-sectional Dependence.

The outcome of the cross-sectional dependence test is displayed in Table 4. From the results, we fail to reject the alternate hypothesis of cross-sectional dependence. This implies that there is evidence of a spill-over effect across countries in the panel. In other words, a change in any of the variables in one country may have some level of effect in another country. Evidence of a cross-sectional dependence may provide policymakers with the needed information to account for issues pertaining to environmental externalities in policy formation. To control and address the issue of the spill-over effect, panel models that are robust to cross-sectional dependence in the panel data are therefore employed. Doing this improves the robustness of the outcome of such estimations as noted by Eregha et al. (2021).

3.3. Panel Unit root Test

The present study used a second-generation panel unit root to address the issue cross sectional dependence (CD) that was detected in the previous stages. To this end, the study employed the Cointegrated Augmented Dickey Fuller (CADF) unit root test to ascertain whether unit roots exist among variables as reported in Table 5. The test result shows robustness in the presence of the spill-over effect. Thus, it is observed that except for trade liberalisation and economic growth, all other factors are non-stationary at level. However, at the first difference they all became stationary at 1%, 5%, and 10% significance levels. The result thus provides the basis to choose an estimator to examine the nexus between the variables.

3.4. Cointegration Analysis

The summary of the cointegration test results is shown in Table 6. The cointegration test is performed to determine the presence or otherwise of a long run interaction involving the studied factors. The outcome of the test illustrates a strong robustness considering their high probabilities. This implies that the variables are strongly cointegrated across panels demonstrating the presence of a long run nexus between the study coefficients. In other words, for the period 1990 to 2020, there appears to be long-term movements between dependent variables and the covariates in both individual countries and the aggregate economic bloc. The outcome however provides a strong basis to proceed with the present study's objectives of determining the long run nexus between the study variables

3.5. Long run Determinants of Renewable Energy consumption

Having established that the variables are heterogeneous across panels with spill-over effects due to the presence of cross-sectional dependence and considering the established possibility of long run interactions among the variables, the study proceeds to examine the impacts of the understudied variables on renewable energy consumption. More emphasis is placed on the roles of technology innovation and trade as the principal targets of investigation for the study's samples (the BRICS, the MINT, and the full sample). The outcomes of the estimations are displayed in Table 7.

Firstly, the result reveals a significantly negative impact of technology innovation on clean energy intake for the BRICS countries but a positive and significant influence on renewable energy consumption in the MINT countries (Khan et al., 2022). As seen in Table 7, this result demonstrates that a rise in renewable energy consumption can be linked to a significant investment in technological innovations in MINT countries by the percentage of the innovation elasticities, however, this is not the case in BRICS countries. In other words, the result supports advocacies for the development and use of green technologies in the MINT countries thereby, confirming related findings from extant studies (André et al., 2021; Yasmeen et al., 2022). The variation in outcomes between BRICS and MINT nations can be attributed to the renewable energy production per capita, such that countries with higher renewable energy per capita tend to gain less from technological innovation compared to countries with lower renewable energy per capita (Solarin et al., 2022).

As for trade liberalization, the result again reveals that trade liberalisation is positive and statistically significant at 5% for BRICS countries (Alam & Murad, 2020; Han et al., 2022) but statistically insignificant in both the full sample and MINT countries. This shows that trade can play desirable roles in renewable energy consumption and the findings are not a surprise considering that a country like China in the BRICS bloc plays a significant role in global trade. The positive sign of trade liberalisation implies that when trade liberalization is promoted by removing or minimizing trade barriers between nations, it can motivate the transfer of green technologies to support renewable energy development. The result can be attributed to the competitive nature of foreign markets.

Furthermore, Table 7 reveals that renewable energy consumption decreases with increasing economic growth for all the three samples. The result suggest that renewable energy consumption is negatively elastic with respect to economic growth, thus a percentage increase in economic growth decreases renewable energy consumption by 0.84% (for the full sample), 0.68% (for the BRICS), and 1.0% (for the MINT). However, as it can be observed that, the estimated coefficient is greater in the BRICS countries than in the full sample and MINT countries. Again, this observation is defendable since most countries in the BRICS bloc rank high among the fastest growing economies with fossil energy consumption being a prime driver of economic growth levels (Azam et al., 2021a; Adebayo et al., 2022; Alola et al., 2021). As such, it is most likely to observe fewer desirable impacts of growth on renewables, specifically in this bloc. The result resonates with the findings of Alam & Murad (2020), but contradicts the outcomes of other studies (Omri et al., 2015; Shayanmehr et al., 2023; Tiba & Belaid, 2021) in which it is observed that renewable energy responds positively to the impact of economic growth. Indeed, economic growth inhibits renewable energy development by increasing the demand for energy, leading to a greater reliance on conventional fossil fuels to meet immediate energy needs, while potentially overshadowing investments in renewable energy infrastructure due to their perceived higher upfront costs compared to traditional energy sources. Additionally, rapid economic growth may prioritize short-term economic gains over long-term sustainability goals, resulting in policies and investments that prioritize conventional energy sources over renewable alternatives.

Table 7 further indicates that renewable energy responds negatively to access to electricity in BRICS countries but positively in MINT countries. This implies that while access to electricity decreases renewable energy consumption in BRICS countries, it promotes alternative energy intake in MINT countries. This outcome is plausible for two reasons; first, a higher percentage of BRICS population have access to electricity compared to that of the MINT economies, which can serve as a disincentive for people to adopt alternative energy sources; and secondly, although some MINT countries such as Nigeria have abundance of oil reserves, only about 55% of the population have access to electricity, which may incentivise the population not connected to the national grid to adopt renewable energy sources (Lawal et al., 2024; Olanrele et al., 2020).

In addition, the results also signify a negative impact of environmental pollution on renewable energy in all three samples. A cursory inspection of the outcome reveals that the elasticities are marginally large in the full sample than in BRICS and MINT countries. The outcome of the present study is therefore tangential to another stream of studies (Liu et al., 2020; Ullah et al., 2019). Carbon emissions negatively impact renewable energy development by exacerbating climate change, which can lead to more extreme weather events and natural disasters, affecting the viability and reliability of renewable energy infrastructure such as solar panels and wind turbines (Asongu & Odhiambo, 2021). Additionally, high levels of carbon emissions can perpetuate the dominance of fossil fuels in energy markets, making it challenging for renewable energy sources to compete economically and attract necessary investment (Asongu & Odhiambo, 2022).

Furthermore, the study finds that urbanization promotes clean energy intake in the full sample and BRICS economies, though the impact based on the elasticities are marginally higher in BRICS countries than the full sample. Lastly, industrial reconstruction generates a positive impact on renewable energy in the BRICS countries, while a negative impact on renewable is detected in the MINT countries. These discrepancies are explainable giving the high level of industrialization among the countries in the BRICS bloc in contrast to the level of industrialization in the MINT group.

3.6. Long run Determinants of Environmental Pollution

Table 8 presents results from the Prais-Winsten regression model with panel-corrected standard errors for the full sample, the BRICS sample, and the MINT sample following the estimation of Equation (2). The elasticity estimates for the environmental pollution impacts utilizes the CO_2 indices vis-à-vis the exploration of the impacts of all variables (i.e., renewable energy, technology innovation, trade liberalization, economic growth, access to electricity, urbanisation, and industrial restructuring). When the two samples are combined, all the variables are significant except access to electricity. Specifically, a 1% rise in renewable energy, economic growth, and industrial restructuring will correspond to a 0.69%, 0.71%, and 0.09% decline in environmental pollution, respectively. This indicates an adverse effect of the variables on ecological pollution level. Similar outcomes are observed in the BRICS and MINT countries for alternative energy intake, and economic growth nexus. In the case of industrial reconstruction, a similar inference is drawn for only the MINT countries. The environmental pollution mitigating role of renewable energy consumption in this study confirms findings from Alharthi et al. (2021), Ali et al. (2023), and Anwar et al. (2021). Interestingly, the prevailing economic growth levels suggest that it is environmentally friendly for all three samples. This lends credence to the argument of the EKC hypothesis (Bekun et al., 2021; Adebayo et al. 2022; Radmehr et al., 2023). The result however contradicts the finding of another stream of the extant literature (Ahmad et al., 2020; Eregha et al., 2021). To contextualize the results in the present study, we assume that economic growth on its own does not promote environmental externalities. As such, we consider economic growth in the context of renewable energy consumption and industrial reconstruction. Government's effort to championing the use of clean energies to fuel industrial activities may result in the promotion of economic growth, which may then exert positive externalities on the environment. Also, we can attribute the present study's result to the fact that countries are making heavy investments to reduce labour-intensive production in their industrialization drive. Economies that thrive on labour-intensive industrialisation are usually not energy-efficient and thus encourage environmental pollution (Asongu et al., 2019).

Contrary to the positive externalities generated from the recently discussed variables, technology innovation, trade liberalisation, and urbanization exert negative environmental externalities on the environment in the full sample. To be precise, trade liberalization, technology innovation, and urbanization all have a positive influence on environmental pollution by the values of their elasticities. Interestingly, a similar trend is observed for technology innovation in both the MINT and BRICS countries. The result confirms the empirical finding of Erdogan (2021) but contradicts the works of Adebayo (2021), Shan et al. (2021), Villanthenkodath (2020). The outcome of the current study's result could be attributed to the poor investments and prioritisation of research and development in these countries. Similarly, the outcomes observed in BRICS and MINT countries, gives credence to the elasticities observed in the full sample. The reason could be attributed to weak environmental regulations. That is the lack of enforcement or weak environmental regulations attracts foreign organizations that do not prioritise environmental protection and hence contribute to environmental pollution. This result aligns with the works of Azam et al. (2021), Dou et al. (2021) Li & Haneklaus (2022) but not with Eregha et al. (2021) who have reported a negative effect for their full sample and a positive effect for oil-poor economies. Interestingly, while the positive elasticities recorded for BRICS countries agrees with the full sample, that of the MINT economies is observed as negative. This implies that while urbanisation deteriorates the environment in BRICS countries, it serves a mitigating role in MINT countries. The environmental pollution role of urbanisation recorded in BRICS economies is in consonance with the extant literature (Azam et al., 2021; Erdogan, 2021; Faisal et al., 2021; Lee et al., 2022; Qayyum et al., 2021), whereas the mitigating role found in MINT countries support the study of Kongkuah et al. (2022) that argues that urbanization reduces environmental pollution through the effect of economies of scale. Thus, due to economies of scale resulting from urbanisation, the overall resource use decreases thereby causing a decline in environmental pollution. Lastly, the estimated elasticities for access to electricity is significant for MINT and BRICS countries but not for the full sample. The result suggests that access to electricity decreases environmental pollution in BRICS countries; however, it promotes pollution in MINT countries. The negative impact of access to electricity in BRICS countries is aligned with Bilgili et al. (2022). This could be attributed to the hydroelectricity power generation potential of BRICS countries. Indeed, Brazil, Russia, and India are among the world's leading hydroelectricity power generators.

4.0. Conclusion, Implications, Caveats and Future Directions

The current study has investigated the role of technology innovation and trade liberalisation in promoting renewable energy consumption in BRICS and MINT countries.

However, to minimize variable omission trap and improve the robustness of the overall findings, the study further accounted for more factors including economic growth, access to electricity, urbanisation, and industrial reconstruction as control variables. Thereafter, the study performed a series of tests using second generation approaches before proceeding to investigate the main objective of the study using the Prais-Winsten regression model with panel-corrected standard errors (PCSE) and the Driscoll-Kraay standard errors for robustness checks.

In summary, the following main findings are established: firstly, there is evidence of heterogeneity among the variables coupled with the confirmation of cross-sectional dependence, and cointegration. Secondly, the panel result on the determinants of renewable energy reveal negative elasticities for technology innovation in both BRICS countries and the full sample but a positive elasticity in MINT countries. This suggests that while technology innovation is associated with decreasing renewable energy consumption in MINT BRICS countries, the former increases the latter in MINT countries. The outcome recorded in MINT countries is the desired outcome for environmentalists since it implies environmental quality is being improved by means of more renewable energy consumption. This outcome could be because of the significant investments being made by MINT countries with regards to the promotion and development of green technologies. The results for the BRICS countries are equally important because it raises questions about the nature of policy measures that need to be formulated to ensure outcomes similar to the MINT countries have achieved.

With regards trade liberalisation, the outcomes show that the elasticities are negative for the full sample and MINT countries but positive for BRICS countries, suggesting that trade liberalisation reduces environmental pollution through the promotion of renewable energy consumption in BRICS countries. This argument could be premised on the pollution-halo hypothesis whereas as a result of strict environmental regulations, multinational companies are forced to comply with the environmental regulations of the host country by opting for environmentally friendly energy sources and technologies for their production processes. The outcomes of economic growth and environmental pollution reveal a negative impact on renewable energy consumption for all samples. However, the results reveal a greater impact in MINT countries compared with that of BRICS countries and the full sample. Furthermore, the estimated elasticities for access to electricity show a decreasing effect in BRICS countries but a positive impact on MINT countries. Lastly, urbanisation and industrial restructuring promote renewable energy consumption in BRICS countries but inhibits renewable energy consumption in the MINT countries. The inhibiting effect in MINT countries during their industrial restructuring phase would be attributed to their reliance on brown energy sources.

In addition, the study's outcome based on the second model suggests that renewable energy, economic growth, and industrial reconstruction all have negative elasticities, which imply that they generate positive externalities on environmental quality in all three samples. However, whereas BRICS countries generate higher environmental externalities from renewable energy consumption compared to the other samples, MINT countries generate theirs from economic growth and industrial reconstruction compared with BRICS and the full sample. On the contrary, the estimated elasticities for technology innovation and trade liberalisation are positive. This suggest that while technology innovation generates negative environmental externalities in MINT countries and the full sample, that of trade liberalisation is observed in BRICS countries and the full sample. In addition, whereas access to electricity produces positive environmental externalities in BRICS countries, negative externalities are recorded in MINT countries. Finally, urbanisation produces negative environmental externalities in the full sample and BRICS countries but positive externalities in MINT countries.

4.1. Policy Recommendations

These results evidently contain important insights for policy formulation. As such, we make some policy suggestions that could help governments and policymakers to ensure that positive environmental externalities are generated from economic and technological progress. Based on the empirical evidence provided in this study, environmental pollution can be curtailed via renewable energy consumption by promoting technology innovation. It is therefore imperative for BRICS countries to scale-up investments in technological innovations and development, particularly through research and development (R&D). Specifically, universities and other research institutions should be well funded and given the necessary support to carry out independent and credible research into the development of green technologies that will promote renewable energy consumption and generate positive environmental externalities. The potential of trade liberalisation to promote renewable energy consumption in BRICS countries is indicative of the fact that the former can positively impact environmental quality. It is therefore imperative for authorities to strengthen their countries trade regulations and enforce them to the latter to ensure that foreign companies do not use the host nation as a dumping site for technologies that work against the promotion of renewable energy consumption. This policy measure is justified by the pollution mitigating role of renewable energy as seen in the second model.

Furthermore, if appropriate policy measures are formulated to support renewable energy consumption via technology innovation and trade liberalisation, economic growth can produce positive environmental externalities as shown by the outcomes of the second model. Thus, governments must harmonise their trade and economic growth policies to ensure that they gravitate towards environmentally friendly economic growth trends. We believe that the policy suggestion for the technology innovation is also beneficial for access to electricity. Thus, promoting technology innovation would likely influence access to electricity generated from renewable sources which will in turn result in an increase in renewable energy consumption. Finally, given that achieving favourable environmental quality requires a collective effort, foreign organizations should take advantage of the opportunities provided through trade liberalisation to invest in innovative green technologies in host economies in order to generate positive environmental externalities on a global scale.

4.2 Limitations and Direction for Future Studies

The present analysis only focuses on these three economic blocs. A major limitation is that findings may not be generalizable in some circumstances due to several factors like differences in both economic and energy phenomena across the globe from one country or region to another. Hence, future studies can strategically explore the determinants of renewable energy usage for other blocs across the globe within the established framework of the current study while keeping the analysis period wider. Other robust empirical approaches can be employed within the remit of a broader panel of developing countries in order to increase the generalisability of corresponding findings,

It is also possible to explore the advantages of any other beneficial empirical approaches for a study like this to broaden policy recommendations for renewable energy development in the future.

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Table 1.Description of Variables

Name of Indicator	Abbreviation	The unit of Variable Measurement	Source
Renewable energy	Ren	% of total final energy consumption	WDI
Technology innovation	TI	Patent applications, residents	WDI
Trade Liberalization	TR	Trade (% of GDP)	WDI
Economic growth	Y	GDP per capita (constant 2015 US$)	WDI
Access to Electricity	ATE	Access to electricity (% of population)	WDI
Environmental Pollution	CO_2	CO2 emissions (kg per 2015 US$ of GDP)	WDI
Industrial restructuring.	SER	Services, value added (constant 2015 US$)	WDI
Urbanisation	UR	Urban population growth (annual %)	WDI

Source: Compiled by the authors

Table 2. Summary Statistics

Variable	lnren	lnti	lntr	lny	lnate	lnco2	lnur	lnser
Full sample								
Obs	261	253	279	279	247	261	264	278
Mean	3.089998	7.856508	3.726966	8.311049	4.414016	-0.37136	0.79408	26.7242
Std. Dev.	0.93741	2.197843	0.362635	0.801871	0.2776988	0.668158	0.818413	0.983575
Min	1.157038	2.484907	2.71837	6.268178	3.306887	-1.55845	-4.25649	24.69356
Max	4.485816	14.15198	4.705712	9.395873	4.60517	0.792825	1.6944	29.68514
BRICS								
Obs	145	153	155	155	136	145	140	154
Mean	2.899221	8.93573	3.635695	8.28655	4.475524	-0.05126	0.574077	27.1088
Std. Dev.	0.9794	1.951616	0.394285	0.8623	0.1814637	0.715953	1.017839	1.007427
Min	1.157038	4.927254	2.71837	6.268178	3.908242	-1.5318	-4.25649	25.23413
Max	4.071637	14.15198	4.705712	9.246711	4.60517	0.792825	1.526424	29.68514
MINT								
Obs	116	100	124	124	111	116	124	124
Mean	3.328469	6.205297	3.841055	8.341673	4.338655	-0.77149	1.04247	26.24655
Std. Dev.	0.826041	1.376203	0.280996	0.721534	0.3487686	0.27711	0.379636	0.707822
Min	2.193384	2.484907	3.03122	7.254249	3.306887	-1.55845	0.346684	24.69356
Max	4.485816	9.008836	4.566286	9.395873	4.60517	-0.29018	1.6944	27.3953

Table 3a. Pairwise Correlation Analysis

	lnren	lnti	lntr	lny	lnate	lnco2	lnur	lnser
lnren	1							
lnti	-0.340***	1						
lntr	-0.521***	-0.0665	1					
lny	-0.646***	0.202**	0.122	1				
lnate	-0.527***	0.439***	0.218**	0.724***	1			
lnco2	-0.370***	0.265***	0.432***	-0.364***	-0.212**	1		
lnur	0.613***	-0.314***	-0.0592	-0.426***	-0.363***	-0.109	1	
lnser	-0.202**	0.881***	-0.138	0.309***	0.536***	-0.0953	-0.197**	1

$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

Table 3b. Pesaran–Yamagata homogeneity test results

Test	Value	p values
Delta	7.301	0.000***
0adj.	9.677	0.000***

Table 4. Cross-sectional Dependency Results

Equation (1)	Pesaran CD	Pesaran scaled LM	Breusch-Pagan LM	Bias-corrected scaled LM
lnren	22.17215***	61.91507***	561.3668***	61.75435***
lnti	16.77171***	50.89269***	467.8388***	50.74269***
lntr	8.206152***	27.90773***	272.805***	27.75773***
lny	30.05467***	102.8215***	908.4693***	102.6715***
lnate	15.30165***	48.56134***	448.0566***	48.41134***
lnco2	11.0871***	32.56028***	312.2831***	32.39956***
lnur	15.34692***	43.80141***	407.6673***	43.65141***
lnser	31.50456***	113.2846***	997.2517***	113.1346***

Table 5. CADF Panel Unit Root Test

	CADF	
Model	I(O)	I(1)
lnren	-1.834	-3.144***
lnti	0.132	-3.275**
lntr	-2.663**	-4.326***
lny	-2.867***	-2.597*
lnate	-0.546	-5.979***
lnco2	-1.368	-2.752 **
lnur	2.322	-4.249***
lnser	-1.675	-4.012***

Table 6. Model one (lnren lnti lntr lny lnate lnCO_2 lnur lnser)

Hypothesized No. of CE(s)	Fisher Stat.* (from trace test)	Prob.	Fisher Stat.* (from max-eigen test)	Prob.
None	431.7***	0.0000	122.7***	0.0000
At most 1	233.7***	0.0000	237.3***	0.0000
At most 2	174.7***	0.0000	83.06***	0.0000
At most 3	164.2***	0.0000	90.14***	0.0000
At most 4	122.5***	0.0000	76.32***	0.0000
At most 5	82.55***	0.0000	61.68***	0.0000
At most 6	48.14***	0.0000	31.63**	0.0005
At most 7	37.02**	0.0001	37.02**	0.0001

Table 7.Model 1 Results - Full and sub-samples LnRen dependent variable

	Full Sample		**BRICS**		**MINT**	
	Panel-corrected Main	Driscoll-Kraay Robust	Panel-corrected Main	Driscoll-Kraay Robust	Panel-corrected Main	Driscoll-Kraay Robust
lnti	-0.0043	0.0623	-0.0867***	-0.1751**	0.0558***	0.0869***
	(-0.30)	(-1.45)	(-2.87)	(-2.75)	(-3.68)	(-6.99)
lntr	-0.0197	-0.4024***	0.1437**	0.3476***	-0.0352	-0.0617
	(-0.60)	(-2.83)	(-2.28)	(-3.02)	(-1.01)	(-1.50)
lny	-0.8421***	-0.7423***	-0.6769***	-0.5758***	-0.9964***	-1.0645***
	(-22.34)	(-21.77)	(-18.80)	(-15.70)	(-16.19)	(-16.13)
lnate	-0.1056	0.0928	-0.3391**	-0.9834**	0.1613*	0.3402***
	(-1.28)	(-0.94)	(-2.15)	(-2.39)	(-1.89)	(-4.31)
lnco2	-0.8248***	-0.7628***	-0.9501***	-0.9913***	-0.9989***	-1.1085***
	(-19.36)	(-10.86)	(-15.74)	(-12.30)	(-11.85)	(-13.20)
lnur	0.0968***	0.2760***	0.1759***	0.2509***	0.15	0.1367
	(-6.09)	(-7.01)	(-4.64)	(-5.12)	(-1.25)	(-1.04)
lnser	0.0379	-0.1518	0.1399*	0.3461**	-0.2699***	-0.3568***
	-0.91	(-1.64)	-1.93	-2.1	(-3.77)	(-8.22)
Constant	9.2467***	13.4570***	6.3408***	2.7396	16.8812***	18.7987***
	(-10.64)	(-7.18)	(-4.49)	(-1.23)	(-9.52)	(-13.47)
NoB	188	188	108	108	80	80
R-Squared	0.967	0.901	0.963	0.966	0.992	0.989
F Statistic		1135.15		1399.4		507.045

Note; $^{*}p< 0.05$, $^{**}p< 0.01$, $^{***}p< 0.001$ and NoB denotes number of observations.

Table 8. Model 2 Results of Full and Sub Sample of BRICS and MINT(LnCO2 dependent variable)

	Full Sample		BRICS		MINT	
	Panel-corrected	Driscoll-Kraay	Panel-corrected	Driscoll-Kraay	Panel-corrected	Driscoll-Kraay
	Main	Robust	Main	Robust	Main	Robust
lnren	-0.6876***	-0.5720***	-0.7207***	-0.5892***	-0.5759***	-0.6291***
	(-20.67)	(-17.20)	(-14.90)	(-8.81)	(-10.34)	(-13.33)
lnti	0.0622***	0.2448***	-0.0002	0.0814*	0.0521***	0.0665***
	(-4.31)	(-16.02)	(-0.01)	(-1.74)	(-3.83)	(-5.46)
lntr	0.0551*	0.1808**	0.3499***	0.5754***	0.0094	0.0197
	(-1.86)	(-2.42)	(-6.95)	(-7.46)	(-0.33)	(-0.78)
lny	-0.7087***	-0.5454***	-0.5659***	-0.3950***	-0.6950***	-0.7666***
	(-24.95)	(-11.82)	(-18.43)	(-8.39)	(-12.74)	(-16.21)
lnate	-0.007	-0.1924	-0.2646**	-0.6974**	0.3073***	0.4154***
	(-0.09)	(-1.47)	(-2.10)	(-2.11)	-4.76	-4.37
lnur	0.0192*	0.1375***	0.1377***	0.1898***	-0.2338***	-0.1128
	-1.81	-5.78	-5.37	-5.83	(-2.70)	(-1.08)
lnser	-0.0934***	-0.4871***	-0.0559	-0.1980*	-0.3810***	-0.3719***
	(-2.62)	(-13.51)	(-1.04)	(-1.78)	(-8.42)	(-8.71)
Constant	9.4312***	17.1791***	8.0541***	10.4411***	15.5110***	15.3190***
	(-11.63)	(-19.52)	(-8.29)	(-6.57)	(-13.23)	(-11.01)
NoB	188	188	108	108	80	80
R-Squared	0.779	0.872	0.906	0.97	0.941	0.954
F Statistic		3314.66		243.952		353.039

Note; $^{*}p< 0.05$, $^{**}p< 0.01$, $^{***}p< 0.001$ and NoB denotes number of observations.