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Political Economy of Clean Energy Transition: The Role of Political Risk and Economic Growth

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Abstract

In the empirical determination of the factors influencing the clean energy transition, the BRICS economies have initiated various policy reforms, such as increased R&D budgets, improvements in technology and political stability. This study analyses the critical role of political risk and economic growth, natural resources, research and development and technological innovation in the clean energy transition in the period 1990–2022. Using panel econometric approaches, this study confirms the heterogeneity of slopes and cross-sectional dependence. Using linear regression with the heteroscedastic panel-corrected standard error approach, the results show that economic expansion, political risk and the quadratic R&D term significantly enhance the clean energy transition. However, natural resources, conventional technological innovation and research and development expenditures are the leading barriers to a clean energy transition in the region. The robustness of these results is validated by a series of panel regressions. Following the empirical outcomes, this study recommends rapid enhancement of the research and development budget, strengthening of governance and institutions and investment in technological innovation to attain a sustainable transition towards clean energy sources.

Keywords: Clean energy; political risk; research and development; economic growth; technological innovation; BRICS

JEL Classification: O13, O44, Q51, Q56

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1. Introduction

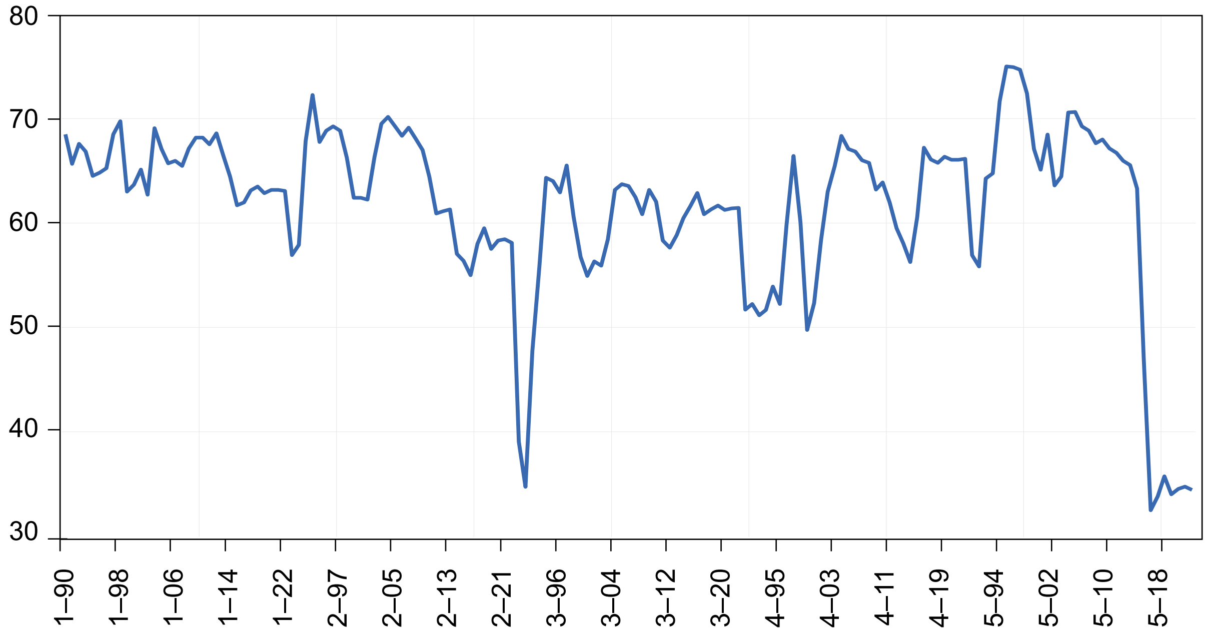
The global economy is rapidly targeting the transition to clean energy, which is basically a move from more conventional fossil fuel-based energy to renewable options, such as solar, wind, hydro and biomass. This is being driven by the imperative to diminish the impacts of global warming and to provide an energy supply that is more stable and reliable while stimulating long-term sustainable economic development. Going green/clean decreases greenhouse gas emissions while mitigating the worst effects of climate change. This also helps ensure that all research – including that provided by organizations such as the Intergovernmental Panel on Climate Change (IPCC, 2021) – makes it clear that we need to globally decarbonize as a human race as quickly as possible to avoid climate change consequences (Rockström *et al*., 2017). Such a statement is believed to make one thing particularly clear and that is the coincident overlap of what is good for the environment and for the economy. This indicates that moving to cleaner energy not only saves the planet but also benefits the general public through job creation, energy independence and resilience from energy disruptions. Transitioning to clean energy sources has the following advantages for the public. It optimizes employment opportunities, and hence, income generation in peripheral fields such as production of solar and wind energy (IRENA, 2020a). Energy independence rises when countries decrease their consumption of imported non-renewable energy sources. Moreover, the development of diverse clean energy sources reduces the opaqueness of available capacities and contributes to grid security by reducing the consequences of either natural or artificial disturbances. Thus, this transition aims at achieving economic development, security and reliability of infrastructure (IRENA, 2019b, 2020b).

The role that economic development plays in the successful movement to clean energy is substantial. Researchers have shown that there is a direct association between economic development and green energy in that as economies grow, the need for energy grows and that energy largely comes from investment in newer, cleaner, sustainable sources of energy (Rahman and Velayutham, 2020). Furthermore, once the changeover begins, feedback often occurs in which the changes enable (or often promote) economic growth through the opening of a spate of new opportunities for innovation, employment, attraction of investment from other sources and more. Research conducted by numerous scholars shows empirical evidence of the importance of clean and green energy in economic development in different countries (Apergis and Payne, 2010, 2014). The effect of economic development on moving to cleaner energy itself is contingent on a number of factors, including government support, technological advancements and societal attitudes about sustainability. Nevertheless, identifying the exact impact of economic growth on clean energy is important for formulating appropriate policies.

Certainly, several examples and case studies suggest a direct relationship between the level of economic development and the adoption of green energy. For example, Germany has embarked on the production of excessive energy from renewable resources, thus giving rise to over 0.3 million jobs in the renewable sector and boosting Germany's economy more so through the Germany's Energiewende project. As per BMWK (2021), renewables made up 46% of electricity consumption in Germany. Secondly, Chinese investment in solar technology has led to economic expansion and market supremacy. China was responsible for 70% of the world's solar panel manufacturing in 2019, which has resulted in the creation of millions of employment opportunities and boosting economies through renewable energy technologies (IRENA, 2020a). Thirdly, it is evident from Denmark's Wind Power Revolution where Denmark invested early in wind power to become one of the leading exporters of wind technologies and this contributed immensely to the country's GDP via the exportation of wind technologies (UNCC, 2023). Finally, California's bold renewable energy policies have promoted employment opportunities and economic development. The clean energy industry in the state generated more than 0.5 million jobs in 2019 (E2, 2020). All these instances highlight the importance of clean energy investments in driving economic growth, employment, technological advancement and improved exports.

In addition, political risk influences the attractiveness of clean energy projects to investors. In general, a country with a lower political risk index is seen as more stable, which makes it more conducive for long-term investment in renewable energy infrastructure and technology (Filippini and Hunt, 2011). Low political risk helps investors better predict returns and recover their investments (Kirikkaleli *et al*., 2022; W. Zhang *et al*., 2022). This is especially important on emerging markets, where the development of renewable energy faces greater political risks. In an environment where the rule of law is observed, there is good governance behaviour, the company registration process is transparent and investor protection is well-regulated, all of which are critical for lowering political risks of renewable energy investments (Apergis and Payne, 2014). As shown in Figure 2, the political risk index has fluctuated across the last three decades. Based on the historical data analysis, it can be noted that the political risk index has shown great swings in relation to different regions and countries beginning from 1990 onwards. In most developing and emerging regions, there has been a tendency to declining political risk (Bekaert *et al*., 2014). Meanwhile, political risk increased in certain periods only: for example, due to the financial and economic crisis of 2008, regional conflicts and changes in the international distribution of power. As for the emerging countries, they are characterized by higher fluctuations concerning risk parameters, which may be linked to changes of political regime, economic structure or geopolitical conflicts (Howell, 2014). The factors that may lead to a lower political risk index may comprise stability in governance, quality institutions, stability in policies, aspects of property rights and low incidences of corruption (Komendantova *et al*., 2012). Such factors help investors have a predict-able field which cuts out risks that are usually attached to longer-term renewable energy projects. Political stability fosters the ability of investors to have confidence in the existing policies while proper legal structures safeguard their investments (Wüstenhagen and Menichetti, 2012). It creates the right atmosphere that makes it easier for countries to plan and embark on large-scale renewable projects, thus making countries more investment-friendly for sustainable energy. Nevertheless, the prominent impact of the stated variable is lacking in the literature and it is crucial to address it, particularly in emerging countries.

Figure 1: Political risk in BRICS economies



Source: Authors' own elaboration

Natural resource endowment also influences the viability of transitioning towards cleaner energy alternatives. Economies abundantly endowed with natural resources, especially fossil fuels, could find it difficult to transition from their use. This is because the relationship between resource abundance and green energy adoption is complicated. While abundant fossil fuel reserves offer a cheap and easily accessible energy source (Ozcan and Ozturk, 2019), they contribute to carbon emissions and environmental degradation (Ahmed *et al.*, 2022). Only a push away from producing finite resources and increased awareness of energy security gives countries the impetus to diversify their energy sources and include renewable sources more in their energy mix. The extant literature explores this idea and reveals that an abundance of resources, especially fossil fuel wealth, can act as a barrier against green energy sources. Some of the countries endowed with fossil fuels may have little interest in moving towards renewables since they enjoy the current benefits offered by fossil fuels, not forgetting the related infrastructure already in place (Ahmadov and van der Borg, 2019). On the other hand, countries that do not possess reserves of fossil fuels might have a higher incentive to go for renewable energy to improve energy security and decrease import dependence (Månsson, 2015). Though both variables are positively associated, their relationship may not always be linear. It is important to understand that some of the resource-rich countries have been able to tap into the resource endowment to finance green energy while others, especially resource-poor countries, have cash constraints to finance the transition (Han *et al.*, 2023). Hence, policies aimed at incentivizing renewable energy investments while phasing out fossil fuel subsidies are essential for offering a solution to the inertia that comes with nonrenewable resource dependencies and hastening the adoption of clean energy technologies (Jacobsson and Lauber, 2006).

Research and development (R&D) efforts play a vital role in driving innovation and technological advancement in the clean energy space. While more R&D financing increases innovation and makes it easier for renewable energy technology deployment (F. Yang *et al.*, 2019), it is exceptionally important that this financing be performed in a targeted way so that it can overcome technological barriers and further reduce the costs of deploying renewable energy (Q. Wang *et al.*, 2020). Higher external funding for R&D enables the elimination of technological hurdles and reduces deployment expenditures for renewable energy in several ways. This ultimately brings about increased efficiency of solar panels, turbines and other structures, and the development of new materials increases output and decreases costs. R&D in advanced manufacturing processes leads to better means of production, hence more efficiency. Better power storage systems are necessary to effectively work with fluctuating renewable energy sources and ultimately become economical. Research related to smart grid technologies and enhanced prediction leads to increased effectiveness of incorporating renewable energy sources into existing grid systems and decreasing operational costs. As the adoption figures rise, due to such advancements, the scaling process drives down the manufacturing costs. Altogether, these R&D-driven upgrades make renewable energy cheaper than conventional fossil fuel sources, thus pushing the clean energy shift (Green *et al.*, 2021; Kavlak *et al.*, 2018; NREL, 2021). Moreover, there are requirements of determined R&D effort to work with the public, private, academic and other stakeholders as well as for the gained knowledge to have the greatest impact outside a simulation environment (Binz and Truffer, 2017). As a result, international collaboration and knowledge sharing could be critical in helping many countries achieve their clean energy goals (IRENA, 2020b). In this regard, the present research intends to attract the attention of academics towards this crucial connection.

Moreover, technological innovation translates the R&D push to commercially viable clean energy solutions. However, there could be technological advancements – particularly those driven by traditional, large energy players – that could hinder and slow efforts to move to cleaner sources of energy (Liu *et al*., 2021). Disruptive innovations could drive such changes in the energy mix (Bergek *et al*., 2008). Enabling technologies are developments that enable more energy innovation such as solid-state batteries (Janek and Zeier, 2016), green hydrogen (IEA, 2019) and smart grid technologies assisted by artificial intelligence (Ramchurn *et al*., 2012). On the other hand, potentially negative trends and possibilities include enhancing the technologies of utilizing fossil fuels, thus delaying the use of more sustainable sources (Bui *et al*., 2018), nuclear fusion innovations that may distract from the advancements of renewable energy (Entler *et al*., 2018) and climatic intervention measures that may lessen the pressure of the transition to cleaner sources of energy (Lawrence *et al*., 2018). These examples are important in showing the interdependency between innovation and the shift towards cleaner technologies, pointing at how innovations could propel the use of cleaner energy in some cases and hinder the progress in others. There are also opportunities and ongoing work emerging through advances in materials, nanotechnology and artificial intelligence to address technical challenges and open up brand-new avenues in the renewable energy space (Ganesh *et al*., 2021; K. Khan and Su, 2023). Policymakers must ensure good conditions for technological innovation and entrepreneurship, thus catalysing the kind of systemic change that may be needed to carry out the shift to better use of cleaner energy forms.

Following this discussion, we intend to achieve the following objectives.

1. We intend to examine the influence of the political risk index on the green energy transition, which is a crucial task in the sustainability targets of the BRICS economies.
2. We aim to analyse whether economic expansion or growth has any influence on the clean energy transition.
3. We intend to scrutinize the important role of nonrenewable resources and technological innovation in the clean energy transition as most countries are dependent on traditional nonrenewable energy obtained via natural resource extraction and processing while simultaneously targeting technological development.
4. We intend to explore the linear and non-linear (quadratic) impact of R&D investments on the clean energy transition in the BRICS economies.

This research contributes to the literature by offering a wide-ranging account of the political economy of clean energy conversion in BRICS economies. By examining the complex interplay of factors such as economic development, the political risk index, natural resources, R&D and technological innovation, this study provides a nuanced understanding of the forces facilitating or inhibiting the incumbency of renewable energy. Moreover, by explicating the multifaceted relationships across these variables, it enhances knowledge of the processes that drive or impede the diffusion of clean energy in emerging economies. Our conclusions offer practical recommendations for policymakers, industry stakeholders and scholars seeking to catalyse the transition to sustainable energy systems, thereby extending the literature on sustainable development and climate change mitigation in the context of BRICS countries.

2. Literature Review

Renewable energy deployment and use are currently the most seriously debated topics worldwide. Global economies are rapidly transitioning to clean energy sources (Pakulska, 2021) for three main reasons. Specifically, natural resource demand should be reduced, the environment should be preserved, fossil fuel dependence should be reduced and ecological quality should be improved. Consequently, it is predicted that green energy could command two-thirds of the overall energy supply globally by 2050 (Hassan *et al*., 2024). For European economies, Androniceanu and Sabie (2022) concluded that these economies may enhance the green energy share by 55% while reducing pollution emissions by 55%. Similarly, plentiful research has been performed in the last five years to identify the benefits that are linked with growing clean energy use (Seminario-Córdova and Rojas-Ortega, 2023). Nevertheless, the literature regarding the factors influencing green energy transition is limited in the scientific community, as less attention has been paid to this critical issue. This section describes the available literature that considers green energy in various economic models.

Dolge and Blumberga (2023) investigated the clean energy transition in 27 European economies in the period 2012–2021. The study revealed that per capita green energy source deployment and its share are the leading drivers of overall electricity generation from green energy sources. In panel analyses, Dogan *et al*. (2020), Hieu and Mai (2023) and Xie *et al*. (2023) employed non-parametric approaches to validate the green energy-led growth hypothesis in different regions. Similarly, Ślusarczyk *et al*. (2022) described the constructive correlation between economic expansion and green energy, where higher economic growth improves the clean energy transition. However, recent empirical evidence (Lahrech *et al*., 2023; Muazu *et al*., 2023) contradicts the above hypothesis and asserts the existence of an adverse correlation between green energy and economic expansion. More comprehensively, various regions, including the OECD (Apergis and Payne, 2014; Gan and Smith, 2011; J. Li *et al*., 2020; Yao *et al*., 2019), selected transition countries (Przychodzen and Przychodzen, 2020), African economies (Abanda *et al*., 2012), Brazil (Salim and Rafiq, 2012) and higher-, middle- and lower-income economies (Omri and Nguyen, 2014), have been analysed and it has been concluded that the green energy transition is significantly driven by an increase in economic growth and income levels.

Concerning political risk, E. Wang *et al*. (2022) analysed 32 OECD economies and asserted that economic growth and institutional quality significantly enhance green energy, whereas political risk and economic globalization are harmful to the green energy transition. After facing political risk, foreign investment could be a game changer in the transition towards clean energy (Shimbar and Ebrahimi, 2020). Gatzert and Kosub (2017) examined the factors of green energy in European economies and asserted that policy and regulatory risks are significant in investments related to the green energy transition. Similarly, Burke and Stephens (2018) revealed that political stabilization is a momentous driver in the transition and deployment of green energy. Similarly, Mahjabeen *et al*. (2020) explored the role of institutional quality in green energy and concluded that a robust institutional structure is vital in the shift from fossil fuel to clean energy. For seven OECD economies, Su *et al*. (2021) asserted that not only political risk but also fiscal decentralization, clean energy-related R&D and eco-innovation significantly enhanced green energy transformation in the region during the period 1990–2018.

It emerges clearly from the available literature that political stability has input on the energy transition of several developed as well as developing countries, including the OECD, MENA and G7 economies among others. For OECD countries, Qamruzzaman and Karim (2024) opined that political stability is an essential factor that stabilizes investor confidence and encourages sustainable long-term investment, which is important for clean energy and technological development. In addition, Dagar *et al*. (2024) showed that political stability improves energy security through the provision of political stability for support, which is essential for energy policies and infrastructure in the country. Consequently, stability in politics, allied with fiscal decentralization, decreases CO_2 emissions through the increase of the use of renewable energy and green innovation in OECD economies (Behera *et al*., 2024). Similarly, Al-Tal and Al-Tarawneh (2021) examined the MENA region and found that political stability along with government effectiveness influences energy consumption, hence playing a role in increasing energy efficiency in the most stable governments across the world. However, political stability in relation to energy transition is rather nuanced, thus geopolitical risks can adjust the impacts of governance and economic complexity on sustainable energy practices on OECD markets (Bakhsh *et al*., 2024).

Following the above discussion, BRICS economies' literature on politics and particular policy measures shows a diverse interplay between political conditions and economic outcomes. Stable politics are a very important issue also for economic growth as, according to different studies in BRICS-T countries political stability played a particularly important role in economic performance. For example, Armutçu (2022) revealed that political stability negatively affects economic growth as well as inflation and government expenditures. However, Kesar and Jena (2022) pointed out that political stability complements trade openness to boost economic growth; that is, context and policies matter. Moreover, the link between democracy and economic growth in BRICS-T countries reveals that democratization has a positive effect on economic growth while political stability seems likely to negatively affect economic growth, perhaps because conducting governance is difficult and imposing policy makes it harder for these countries (Sungur and Altıner, 2023). Also, CO_2 emissions in BRIC countries are positively associated with economic policy uncertainty (Oprea *et al*., 2024). According to Ertugrul *et al*. (2019), political and economic stability on these emerging markets is also a decisive factor in financial stability, where political risks and deterioration in these economies are a threat to the financial systems. These findings demonstrate the necessity of well-thought-out policies for these countries which take into account the multidimensional effects of political stability on economic growth and environmental sustainability in BRICS economies.

Regarding the role of R&D and technological innovation, the literature offers diverse conclusions. For instance, Wu *et al*. (2020) examined R&D subsidies in the context of green energy in China in 2009–2015 and concluded that increasing R&D subsidies significantly improved green energy investment. Similarly, Miremadi *et al*. (2019) investigated Nordic economies and asserted that the public R&D budget and knowledge spillover exhibit a noteworthy improvement in clean energy sources. Similarly, Sim (2018) examined the factors of clean energy and environmental quality in Korea. The research concluded that an enhanced level of green energy itself leads to greater R&D investments and decreases pollution emissions in the region. Yao *et al*. (2019) studied OECD economies and revealed that R&D improvement not only encourages the use and transition to green energy but also minimizes the level of fossil fuel energy, which is the major cause of polluting emissions. In contrast, Gan and Smith (2011) analysed OECD economies from 1994 to 2013 and revealed that R&D is insignificant in promoting green and bioenergy supplies.

In the framework of technological progression and natural resources, the literature is diverse and mixed. Specifically, Yuan *et al*. (2023) analysed the role of technological innovation and natural resources in green energy in eleven countries from 1990 to 2020. Using advanced econometric strategies, the study asserted that natural resources are significant in promoting green energy, while technological innovation is harmful to the clean energy transition in the region. In 48 African economies, Nchofoung and Ojong (2023) investigated the period from 1990 to 2020 using non-parametric approaches. Their estimated results showed that natural resource instruments exhibit an encouraging effect on the clean energy transition. Despite the contribution of natural resources to clean energy, there is also a constructive influence of clean energy on natural resource sustainability (Chau *et al*., 2022). Similarly, in the MENA region, B. Li *et al*. (2024) used CS-ARDL and concluded that both natural resources and governance are essential for promoting clean energy in the region over the last three decades. However, Shinwari *et al*. (2022) claimed that natural resource volatility is adversely connected with investment in the clean energy transition. Therefore, natural resources should remain stable to stimulate a transition to clean energy.

On the other hand, the latest study by Yan *et al*. (2024) used AMG and PMG estimators and concluded that technological innovation is harmful to the clean energy transition in BRICS countries from 1997 to 2019. Similarly, the positive impression of technological innovation was also validated by Hoa *et al*. (2024) in ASEAN countries. In contrast, Saadaoui *et al*. (2024) revealed that the green energy transition is significantly driven by an increase in technological innovation and income level. Apart from conventional technological progress, scholars such as J. Li *et al*. (2020), Su *et al*. (2020) and Alvarez-Herranz *et al*. (2017) have analysed various panel and time series economies for different time periods and concluded that environment-related technological development significantly improved the consumption and transition of green and clean energy sources.

3. Theoretical Depiction, Data and Methods

3.1 Theoretical framework

The connection between economic growth and the shift towards clean energy is a basic idea grounded in environmental economics as well as sustainability theory. As explained by Grossman and Krueger (1995), the environmental Kuznets curve hypothesis infers that as development occurs, the rates of polluting the environment increase, but at higher rates of income per capita, the pollution rate decreases. This is supported by the ecological modernization theory (Mol and Spaargaren, 2000), according to which developed countries can attain environmental enhancement at the same time as economic expansion with better technology and institutional change. Greater financial and institutional capacity of emerging markets and developing economies are also confirmed by the WB (2012), where higher-income economies are found to have a greater ability to invest in renewable infrastructure. The process starts with economic development to the level of achieving higher per capita income. It also helps in creating better environmental awareness among consumers and inculcating a higher market push towards cleaner forms of energy. The enhanced investment prospects further allow the construction of extensive renewable power infrastructure, thereby providing exclusive clean power utilization and decreased carbon intensity of economic sectors. In contrast, within the institutional economics concept by North (1990), the political institutions are pivotal and guide efficiency and investment. This would apply more to clean energy transitions that need large sums of investments and for which policy certainty spans across long periods in the future. Regarding this, Baker *et al*. (2016) showed that policy risks affect investment in renewable power significantly. Institutional quality, as outlined by Acemoglu and Robinson (2013), is expected to provide a cleaner energy environment since countries with lower relative political risk display better protection of property rights and policy certainty. Political stability and institutional quality affect the certainty of investment in renewables. The strength of policy consistency and regulatory frameworks are determinants of clean energy incentives. These institutions define the investment environment and therefore define, to some extent, the rate of investment in clean energy infrastructure deployment.

The connection between resources and clean energy transition enhances resource curse hypothesis (Sachs and Warner, 1995), whereby countries abundant in natural resources are strategically locked out from transition. It has become quite evident that this phenomenon plays a major role in influencing the clean energy transition initiatives. Consequently, the natural resource endowment theory, which is backed up by the data from IRENA (2019a), maintains that resources in a country determine the transition pathways of countries. The nature of investments in renewable resources determines the market development paths of clean energy. The availability of natural resources, for that matter, dictates the tenor of national energy security imperatives and economic rationales. These factors define infrastructure development trends and reveal the modalities of the comparative advantages in energy production techniques. It focuses on how these elements affect the path and rate of clean energy transitions. Furthermore, the theoretical framework is underpinned by the technological paradigm and technological trajectory frame of Dosi (1983). This is supported by the work of Arthur (1989) on technological lock-in and path dependence of technology, which makes both analysis of barriers and opportunities of energy transition possible. The study provided empirical evidence of how induced innovation works through market signals, building on the theory of induced innovation first formulated by Hicks (1932) and refined by Popp (2002).

According to the innovational systems theory (Freeman, 1987;Lundvall, 1992) technological learning in the renewable energy sector depends on the interface between research organizations, firms and governments. These activities bring about new discoveries in technologies for improving the performance and efficiency of clean energy systems. These enhancements give rise to cost savings by learning and economies of scale. It also incorporates externalities and knowledge spillover, which enhance broader technological propagation across the energy sub-sector. Such technological development generates reinforcement feedback systems that enhance the pace of the transition to clean energy systems.

3.2 Data and model specification

Following the objectives and discussed literature, we reveal that economic development, political risk, nonrenewable resources, technological progress and research and development are the key instruments used for environmental recovery and determining energy transition in different regions (Dolge and Blumberga, 2023; Miremadi *et al*., 2019; Su *et al*., 2021; Yuan *et al*., 2023). Clean energy entails electricity from sources which generate little or no greenhouse gases and have less environmental footprints than conventional fuel. Sources include solar, hydroelectric, wind, geothermal power and biomass energy, nuclear energy and modernization technologies for the improvement of energy effectiveness or reduction of emissions from existing energy systems (Gielen *et al*., 2019; Markard, 2018). As a result of their nature and development, renewable energy sources are now seen as even more stable than domestically produced fossil fuels. Fossil fuels are affected by price fluctuations and conflicts, while renewable energy is abundant and dispersed all over the world, eliminating energy security concerns as noted by Gielen *et al*. (2019). Subsequently, superior energy storage solutions and intelligent power networks have ensured that intermittency challenges relating to some renewable sources of power are much better addressed, making them reliable for base load power (Jäger-Waldau *et al*., 2020).

Thus, we construct the following research model:

$$RECN_{it} = \alpha_1 + \beta_1 GDP_{it} + \beta_2 PRINDX_{it} + \beta_3 TNRNTSS_{it} + \beta_4 TI_{it} + \beta_5 RDVLP_{it} + \\ + \beta_6 RDVLPS_{it} + \varepsilon_{it} \tag{1}$$

where the key dependent variable is renewable energy use (*RECN*: % of total final energy use), which is used as a proxy for the clean energy transition. However, economic growth (*GDP*: constant USD 2015), the political risk index (*PRINDX*), natural resources (*TNRNTSS*: rents as a percentage of GDP), technological innovation (*TI*: patents of residents and non-residents) and research and development expenditures (*RDVLP*: percentage of GDP) are the explanatory variables. In addition, we include the quadratic term of *RDVLP* (*i.e.*, *RDVLPS*) in the model to examine whether a higher *RDVLP* influences *RECN*. In Equation (1), the intercept is characterized by α, while the slopes of variables are captured by β's and the random error term is signified by ε. Moreover, the time period 1990–2022 is denoted by t for i of the BRICS economies. The reason for considering the period of 33 years is that the data before 1990 and beyond 2022 are not available for several variables. The *PRINDX* data are collected from the ICRG (2023), while the remaining variables are mined from the WB (2024).

3.3 Methodology

We use a comprehensive research method that seeks to establish the link between various economic, political, resource and R&D-related variables and the shift to clean energy. The empirical analysis commences with descriptive statistics to give an overview of the dataset, then a normality test to determine its distribution. To further check the compliance of the model results with the assumptions of the panel data analysis, we employ the technique of slope heterogeneity tests to verify the homoscedasticity of variable relationships across cross-sections, while cross-sectional dependence tests are used to assess for interdependencies of panel units. Unit root tests are conducted to test the stationarity of panel data and a cointegration test is carried out to examine the consistent long-run relationship of the variables. The main analysis uses linear regression with heteroscedastic panel-corrected standard errors due to the possibility of heteroscedasticity in the panel data. In this regard, the cointegration regressions are carried out for enhanced consistency and confirmation of the model results. This methodological approach helps make rigorous statistical measures for the data, taking into consideration various statistical properties of the panel data, address potential problems in this type of analysis, and, consequently, offer a reliable assessment of the results concerning clean energy transition by various economic and non-economic factors. The detailed methodological setup used in this study is given below.

Summarizing the overall information of the data in the empirical examination of time-series information is important. In this respect, the mean, median and range statistics are evaluated. The investigation also calculates the standard deviation for each variable. This statistic designates the basic volatility of the variable. The investigation uses two normality indices: kurtosis and skewness, which have critical values of 3 and 1, respectively.

Following the descriptive summarization and before the stationarity analysis, two diagnostic methods are employed: the cross-sectional dependence (CD) test (Pesaran, 2021) and the slope coefficient heterogeneity (SCH) test (Hashem Pesaran and Yamagata, 2008). Overlooking these diagnostic analyses could lead to misleading results (Wei *et al.*, 2022). Therefore, the performance of these tests is essential when dealing with panel data. The CD test works on the following statistical equation:

$$CD_{Test} = \frac{\sqrt{2T}}{\left[N(N-1)\right]^{1/2}} \sum_{i=1}^{N-1} \sum_{k=1+i}^{N} T_{ik} \tag{2}$$

These estimates offer an indication of cross-sectional independence as H_0. The SCH test, which assesses both the SCH and adjusted SCH statistics, can be performed as follows:

$$\hat{\Delta}_{SCH} = \sqrt{N\left(2k\right)^{-1}}\left(N^{-1}\acute{S} - K\right) \tag{3}$$

$$\hat{\Delta}_{ASCH} = \sqrt{N}\sqrt{\frac{T+1}{2K.\left(T-K-1\right)}}\left(N^{-1}\acute{S} - 2K\right) \tag{4}$$

This test assumes that slope homogeneity is H_0. These tests are important because the BRICS group, while sharing some similarities, contains rather significant structural differences and developmental levels. This analysis confirms whether the relationships of variables are constant across these divergent economies or whether they vary across countries. The cross-sectional dependence test recognises that there are tight economic links between BRICS countries and that they catch international shocks and any dependence is thus effectively captured in the analysis.

To determine the cointegration and long-run coefficients, each parameter of the panel model must be stationary. Therefore, we make a set of unit root assessments. These unit root statistical testing processes were developed by Phillips and Perron (1988; PP), Breitung (2001; Br), Im *et al.*

(2003; IPS), Maddala and Wu (1999; ADF) and Levin *et al*. (2002; LLC). Both the level [I(0)] and first-difference [I(1)] information are tested for stationarity. Concerning H_0, all the variables presume the presence of unit roots. Subsequent to the unit root analysis, we employ the Kao (1999) residual cointegration test to ascertain the probable long-run equilibrium association between variables. This test is a primary instrument when considering panel data in emerging countries. This test is specially devised to test for the nature of long-run relationships between variables and at the same time coping with non-stationary data which is characteristic of macroeconomic time series. Due to its usefulness for panels with relatively shorter time dimensions, this is especially accurate for the BRICS context, where data are often scarce. Furthermore, since many endogeneity-related concerns can be mitigated with this test, its applicability strengthens its suitability for the clean energy transition research area.

The methodology utilized in this study is "linear regression with heteroscedastic panel-corrected standard errors" to evaluate the association between *RECN* (dependent variable) and the following regressors: *GDP*, *PRINDX*, *TNRNTSS*, *TI*, *RDVLP* and *RDVLPS*. The application of this technique to the data in the present study allows an examination of cross-sectional and time-series data within a panel framework and corrects for heteroscedasticity, a common issue in panel data analysis (Greene, 2004). By correcting for heteroscedasticity, the standard errors are adjusted to produce more reliable estimates of the regression coefficients, allowing more accurate statistical inference. The use of this methodology ensures the robustness with which the associations between the variables are captured and the significant factors of the clean energy transition in BRICS economies are identified. Fundamental insights into the use of panel data regression techniques with heteroscedasticity correction have been provided by various empirical studies (Arellano and Bond, 1991; Beck and Katz, 1995). To ensure more reliable tests and confirmations of the results, the research employs panel fully modified ordinary least square (FMOLS) and robust least square (RLS) techniques. However, compared with other techniques, FMOLS has its own advantages in that it corrects endogeneity and serial correlation provides efficient estimates for cointegrated panels and effectively deals with the non-stationary variable. In parallel, RLS has more robustness associated with it in terms of being least affected by outliers; this is an important consideration given the fact that large fluctuations are inevitably associated with the members of the BRICS economy. In combination, these approaches create a comprehensive set of tools that allows considering the distinctiveness of BRICS economies while providing accurate results. The present study benefits from this methodological approach in the context of clean energy transition by allowing a comprehensive analysis of the patterns of interest.

4. Results and Discussion

To empirically examine the model discussed above, we initially analysed the descriptive statistics reported in Table 1. The mean and median values are found to be optimistic for all the variables, which reveals the progressive nature of the considered variables. Nevertheless, there is less variation between these indices. However, there is a noteworthy difference between the range statistics (maximum and minimum). Therefore, we employ the basic volatility measure, *i.e.*, the standard deviation. The outputs indicate that *GDP* is the leading volatile variable, shadowed by *TI* and *RECN*. To assess the normality of the series, we evaluated the skewness and kurtosis. The outcomes reveal that all the variables are positively skewed except the *PRINDX*. However, the output for kurtosis differs from the critical value of 3. Therefore, we conclude that the variables are asymmetrically distributed.

Table 1: Descriptive statistics

	GDP	***PRINDX***	***RECN***	***RDVLP***	***TI***	***TNRNTSS***
Mean	2,160,000,000,000	61.7056	24.84579	0.989645	118303.2	5.459762
Median	1,230,000,000,000	63.29167	18.57000	0.987830	24774	3.855525
Maximum	16,300,000,000,000	75	52.95000	2.432600	1,585,663	21.5027
Minimum	179,000,000,000	32.5	3.18000	0.526940	3,140	0.863775
Std. dev.	3,150,000,000,000	8.301225	17.37756	0.400292	320,021.2	4.523313
Skewness	2.916399	−1.806745	0.15512	1.722386	3.577797	1.650135
Kurtosis	11.09248	6.692529	1.420587	6.059648	14.71659	4.98494

Source: Authors' own calculations

The evaluation of descriptive statistics follows the employment of various panel diagnostic tests. Specifically, it is crucial to analyse the properties of SCH and CD. We use the SCH test (Pesaran, 2021) and the predictions are described in Table 2. SCH and $SCH_{(adj)}$ are significantly different ($p < 0.01$). Hence, the null assumption of the test – homogeneous slopes – can be neglected and we conclude that there is heterogeneity in the panel data.

Table 2: Slope homogeneity (Pesaran, 2021)

	Δ	Prob.
SCH	10.014***	0
SCH(adj)	11.505***	0

Note: *, ** and *** denote significance at 10%, 5% and 1% levels, respectively.
Source: Authors' own calculations

In addition, we use the CD test (Hashem Pesaran and Yamagata, 2008) and the predictions are described in Table 3. The outputs assert that the variables except *RDVLPS* indicate statistical values greater than their respective critical values at $p < 0.01$. Therefore, H_0 of the test – cross-sectional independence – can be neglected and the predictions indicate the presence of cross-sectional dependence between the variables.

Table 3: Cross-sectional dependence (Hashem Pesaran and Yamagata, 2008)

Variable	CD test	Prob.
RECN	10.050***	0.000
GDP	16.718***	0.000
PRINDX	3.750***	0.000
TNRNTSS	9.787***	0.000
RDVLP	5.488***	0.000
RDVLPS	1.589	0.112
TI	10.426***	0.000

Note: *, ** and *** denote significance at 10%, 5% and 1% levels, respectively.
Source: Authors' own calculations

After the diagnostic assessment, it is crucial for the panel data to be free from unit roots. In this sense, we employ a series of unit root tests and the results are presented in Table 4. The predictions indicate that only *PRINDX* is significant at that level. However, the remaining variables (*RECN*, *GDP*, *RDVLP*, *TI* and *TNRNTSS*) are nonsignificant, indicating the presence of structural breaks in the panel variables. Therefore, we analyse all the variables at the first differences. All the variables show statistically significant results ($p < 0.01$). Therefore, H_0 of the tests – unit root presence – can be rejected and the variables are regarded as stationary. Such stationary results permit us to empirically examine the cointegration between the variables.

Table 4: Unit root summary

Test	*RECN*	*GDP*	*PRINDX*	*RDVLP*	*TI*	*TNRNTSS*
Summary [I(0)]						
LLC	1.453	1.230	−7.265***	0.544	0.761	0.252
Br	0.842	3.276	−0.941	0.094	0.466	−2.185
IPS	1.373	1.395	−6.485***	0.996	0.636	−0.029
ADF	5.704	8.820	73.280***	5.695	12.453	7.964
PP	12.713	6.892	17.614*	6.594	9.162	14.892
Summary [I(1)]						
LLC	−2.640***	−3.279***	−5.943***	−3.749***	−7.370***	−5.385***
Br	−2.358***	−0.980	−4.722***	−4.785***	−4.349***	−7.941***
IPS	−2.958***	−2.680***	−6.943***	−4.798***	−5.823***	−7.173***
ADF	29.225***	25.462***	59.228***	40.738***	49.966***	61.253***
PP	295.100***	45.611***	118.815***	90.770***	214.149***	349.422***

Notes: LLC = Levin, Lin & Chu t*, Br = Breitung *t*-stat, IPS = Im, Pesaran and Shin *W*-stat, ADF = ADF-Fisher Chi -square and PP = PP-Fisher Chi-square; *, ** and *** denote significance at 10%, 5% and 1% levels, respectively.
Source: Authors' own calculations

We examine the long-run association between the variables by employing the Kao (1999) residual cointegration approach, and Table 5 indicates the predicted outcomes. The results show that the difference in ADF performance is significant at $p < 0.05$. Therefore, H_0 of the given test – no cointegration test – can be neglected and it is concluded that the variables have a significant equilibrium relationship in the long run.

Table 5: Cointegration test (Kao, 1999)

ADF	**t-stats**	**Prob.**
	−1.771**	0.0383
Residual variance	0.0004	
HAC variance	0.0006	

Note: *, ** and *** denote significance at 10%, 5% and 1% levels, respectively.
Source: Authors' own calculations

Due to the presence of cointegration, we employ a parametric approach to investigate the specific impact of all the factors on *RECN* and the empirical outputs are presented in Table 6. We determine both the positive and negative factors of *RECN* in the BRICS economies. Specifically, the results indicate that *GDP*, *PRINDX* and *RDVLPS* improve *RECN*, where the influence is found to be significant only for *GDP* and *PRINDX* in the long run. Economic expansion sometimes makes investment capacity higher, so the country can spend more on research into clean energy facilities and inventions. In general, growth in economies may extend the call to energy, thus spurring the development of new emission reduction technologies. In fact, the growth process also increases the level of citizens' and policymakers' awareness of environmental problems and drives higher support for the respective clean energy projects. This implies that with lower political risks, long-term returns are assured because clean energy projects usually require huge initial capital investments. A stable political environment is usually a stable policy environment, meaning that long-term clean energy policies and strategies can be affected. It also stabilizes the country and attracts foreign investment in technology transfers in the clean energy industry. Furthermore, lower political risk normally implies that the BRICS economies have better institutions and governance structures which are relevant for the proper management of the intricate change towards clean energy systems. Hence, these elements contribute to the fact that the environment is much more suitable for clean energy development, adoption and upscaling.

These estimates are in line with empirical estimations (Dogan *et al*., 2020; Hieu and Mai, 2023; Mahjabeen *et al*., 2020; Miremadi *et al*., 2019; Su *et al*., 2021; Wu *et al*., 2020; Xie *et al*., 2023). On the other hand, our study has shown that *TNRNTSS*, *RDVLP* and *TI* are substantial and harmful factors of *RECN* in emerging countries. The significance level of these variables is noted as $p < 0.01$. The adverse influence is found to be aligned with several various empirical works, such as Hoa *et al*. (2024), Nchofoung and Ojong (2023) and Yuan *et al*. (2023). The detrimental impact of *TNRNTSS* and *TI* on *RECN* in BRICS economies can be discussed in terms of the following linkages. These results are also consistent with the resource curse theory because they reveal that rich fossil fuel resources lead to economic and political conditions conducive to sustaining current energy structures. Where large reserves of oil and gas exist, in BRICS countries as an example, we can characterize the path dependency by fixed and heavily invested-in technology, people and revenues, which create institutional inertia. This is well illustrated by Russia's dependence on hydrocarbon and Brazil's development of deep-water oil. The above-mentioned negative impact is probably due to these countries focusing most of their innovation capabilities towards improving the efficiency of the use of non-renewable resources, rather than investing in renewables. Moreover, the mature technological infrastructure and networks in use in the BRICS countries align the technological systems with conventional energy sources, thereby promoting lock-in technological effects. The influence of fossil fuel lobby groups and ownership of energy corporations also sustains this trend, complicating the redirection of technological channels towards green energy policies even if it offers great advantages in the long run.

Table 6: Primary results (linear regression, heteroscedastic panel-corrected standard errors)

Variable	Coef.	Std. er.	z	p > |z|	95% CI	
GDP	1.035***	0.103	10.070	0.000	0.834	1.237
PRINDX	0.804***	0.214	3.760	0.000	0.385	1.223
TNRNTSS	−0.693***	0.068	−10.170	0.000	−0.826	−0.559
RDVLP	−0.414**	0.186	−2.220	0.026	−0.778	−0.049
RDVLPS	1.011	0.741	1.360	0.173	−0.442	2.464
TI	−0.811***	0.096	−8.470	0.000	−0.999	−0.623
Constant	−8.719***	0.986	−8.840	0.000	−10.652	−6.786

Note: *, ** and *** denote significance at 10%, 5% and 1% levels, respectively.
Source: Authors' own calculations

After obtaining the empirical results, we test the authenticity of the research model by employing two robustness approaches. Specifically, we utilize panel FMOLS and panel RLS; the empirical outcomes are presented in Table 7. *GDP*, *PRINDX* and *RDVLPS* are the leading factors of *RECN* in the BRICS region. These results are consistent with the outcomes obtained via earlier estimators and are aligned with evidence offered by previous studies (Burke and Stephens, 2018; Gatzert and Kosub, 2017; Przychodzen and Przychodzen, 2020; Sim, 2018; Ślusarczyk *et al*., 2022; Yao *et al*., 2019). Similarly, the adverse effects of *TNRNTSS*, *RDVLP* and *TI* strongly influence the *RECN*. These estimates are consistent with and in line with earlier predictions, as evidenced by B. Li *et al*. (2024) and Yan *et al*. (2024). Despite the difference in magnitude, the overall long-term influence of each regressor has been confirmed and validated.

Table 7: Robustness tests

Panel FMOLS			Robust least square	
Variable	**Coef.**	**Std. er.**	**Coef.**	**Std. er.**
GDP	0.232***	0.004	0.230***	0.059
PRINDX	0.188***	0.015	0.197	0.283
TNRNTSS	−0.998***	0.015	−1.031***	0.071
RDVLP	−0.197***	0.016	0.197	0.228
RDVLPS	1.702***	0.015	1.824**	0.918
TI	−0.272***	0.010	−0.276***	0.088

Note: *, ** and *** denote significance at 10%, 5% and 1% levels, respectively.
Source: Authors' own calculations

4.1 Discussion

In the context of the BRICS economies, economic growth is a key driving factor of the transition to cleaner energy. As these countries expand economically, there is an increased demand for energy, leading to investments in cleaner, more sustainable sources. Research findings of Rahman and Velayutham (2020) and T. Zhang *et al*. (2023) demonstrate that rapid economic expansion leads to an increase in investment in renewable energy infrastructure and technologies. Furthermore, an expanding economy fosters inventions alongside new possibilities for policy intervention that favours clean energy adoption. Economic growth thus acts as a catalyst for the move towards cleaner energy sources in BRICS economies. Similarly, the level of political risk significantly affects the attractiveness of investment in cleaner energy initiatives. As is evident, lower political risk spurs both domestic and foreign investors to inject funds into clean energy projects (Filippini and Hunt, 2011). Conversely, high political risk may deter investment due to uncertainties and potential regulatory obstacles. Thus, favourable politics characterized by stable governance and policies that support the clean energy transition in BRICS economies provide a climate conducive to investment and innovation in the sector. Moreover, the linkage between the quadratic term for research and development and the clean energy transition suggests that increasing R&D expenditures initially stimulate innovation and enable the adoption of clean energy technologies. However, marginal returns start to falter beyond a certain point. This trend is supported by Lin and Xie (2023) and Z. Khan *et al*. (2020), among others, who have pointed to the role of R&D investments focused on driving the clean energy transition. It is important, however, to ensure that R&D investments are allocated efficiently to maximize their impact.

Conversely, the inverse relationship between natural resources and a clean energy transition implies that economies overly dependent on traditional fossil fuel resources may face challenges in switching to cleaner alternatives. The findings of Akkemik and Göksal (2012) and Kebede *et al*. (2015) show that an abundance of natural resources can dissuade investment in renewable energy given that they offer cheaper and more readily available sources of energy. Thus, a reliance on natural resources may hinder efforts to switch to cleaner energy technologies in BRICS economies. Although technological innovation is typically associated with facilitating a clean energy transition, a negative relationship indicates that this link may be complicated in various ways. For instance, studies such as those by Z. Yang *et al*. (2018) and Corvaglia (2014) underscore that certain technological advancements, particularly those related to fossil fuel extraction and use, could deter the adoption of clean energy sources. Furthermore, swift technological advancements in traditional energy sectors could delay investment in, and ultimately the adoption of, renewable energy technologies, thus impeding the clean energy transition in BRICS economies. Therefore, emerging economies must consider policy-level changes to abandon their dependence on fossil fuels and boost the transition to clean energy to achieve sustainable development goals.

5. Concluding Remarks

Our in-depth study of three decades of clean energy transitions in the BRICS countries uncovered the multifaceted forces driving this critical global shift. Economic growth is at the centre of this movement, illuminating the synergistic relationship between prosperity and ecological resilience. The burgeoning growth of these economies has spurred greater demand for energy, propelling the expansion of renewable energy infrastructure and technology. However, the trajectory of economic growth must be managed carefully to align with the objectives of sustainable development – to strike a delicate balance between growth and safeguarding the environment. Moreover, our study underscores the critical role of political stability and regulatory certainty in enabling clean energy transitions. Countries with lower political risk indices are more likely to attract investments in clean energy, signifying the imperative for an enabling context for sustainable energy development – garnering sound governance, transparent regulatory frameworks and proactive policy measures to inspire investor confidence and long-term sustainability.

Our findings also revealed the intricate dynamics surrounding R&D, natural resources and technological innovation. While initial R&D expenditures stimulate innovation and accelerate the uptake of clean energy, diminishing returns stress the urgency of strategic resource commitment. Additionally, an abundance of natural resources and certain technological innovations were found to obstruct the transition to cleaner energy sources – revealing the intricate interplay of economic, technological and environmental factors. In light of these facts, we recommend that policymakers in BRICS economies assume a comprehensive and farsighted approach, as they embark on this journey towards clean energy. This entails facilitating the harmonization of environmental considerations in economic policies, reinforcing governance structures and earmarking targeted investments in clean energy R&D and infrastructure. It can be expected that by rallying around these principles and fostering collaboration, these countries can collectively navigate towards a sustainable and low-carbon path, ensuring energy security, economic growth and ecological robustness for future generations.

5.1 Summary of main findings

The study on BRICS economies reveals a complex interplay of factors influencing the clean energy transition:

- The evidence obtained implies that economic development and low political risk positively influence the clean energy transformation. As the BRICS economies are rapidly enhancing their economic growth, which shows their capability of implementing clean energy technologies.
- Surprisingly, natural resource rents and technological advancement were found to negatively influence clean energy transition. This could be due to either the "resource curse" effect or the diffusion of the fixed effects of earlier technologies.
- Expenditures on research and development have a U-shaped association with clean energy transition. Linear research and development significantly reduces the level of transition, but transforms into a positive force once the research and development expenditure reaches a maximum (quadratic) level.

5.2 Policy implications

According to the empirical analysis, the BRICS economies' policymakers should strengthen political and economic stability to encourage the clean energy transition. This requires, therefore, functioning policies that help with the economic aspects and minimize the political risks since they lead to increased use of clean energy. However, the problem arises that natural resources and innovation in technology affect clean energy transition unexpectedly and need proper management. Furthermore, policymakers need to come up with measures to manage the resource curse, possibly through re-investing the revenues from the natural resources in clean energy. Our findings imply persistent and increasing R&D funding due to its U-shaped connection with clean energy transition, which may only worsen if the expenditures are discontinued or decreased. Outcomes generated from conventional fossil abundance and the existing structure of technological systems should be offset by specific clean energy policies with incentives and/or regulation. To overcome the challenges pertaining to institutional quality and natural resources, the BRICS countries should create sovereign wealth funds for green energy following Norway's model. Sure ways of diversifying capital for renewable investment include enhancement of standard institutional structures such as independent regulatory authorities and clear licensing and dispute resolution systems. Establishing compulsory requirements for purchasing of clean energy by state-owned companies and creating green investment banks could be used to rebalance natural resource sales back into clean energy. Also, clear policy guidelines for implementation of technology transfer and bilateral/international cooperative projects on green energy between BRICS countries would ensure the breaking of technological lock-in, as well as optimising the innovation potential of member states. Also, understanding difficulties familiar to all BRICS countries and their cooperation in sharing knowledge and technologies could be the way to solve these issues. The policymakers should also take a long-term view and should review and modify the measures taken based on what is manifested on the ground in a bid to optimally enhance the pace of the change towards clean energy.

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