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Examining the Nexus between Education, Financial Development, Domestic Capital Formation, Openness and Renewable Energy Consumption in BRI

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ABSTRACT

This study investigates the impact of financial, trade, and economic openness on energy consumption, focusing on renewable, nonrenewable, and fossil energy sources in Belt and Road Initiative (BRI) nations. The BRI framework, introduced by China in 2013, emphasizes economic collaboration and infrastructure development, including renewable energy projects. As participating nations navigate energy transitions to address climate change and achieve sustainable development, understanding the role of openness is crucial. Motivated by the dual challenges of energy security and environmental sustainability, this study explores how openness influences energy consumption patterns and identifies pathways for policy intervention. Using data from 2004 to 2020, the study employs advanced econometric techniques, including Cross-Sectionally Augmented Autoregressive Distributed Lag (CS-ARDL) and Nonlinear ARDL models, to examine short- and long-term relationships. Control variables such as urbanization, financial development, and education are integrated to provide a comprehensive understanding of the dynamics. The analysis reveals that financial openness positively impacts energy consumption across all types, with a significant contribution to renewable energy in the long term. Trade openness facilitates technology transfer and renewable energy adoption, while economic openness through foreign direct investment (FDI) supports clean energy projects but also sustains fossil fuel reliance in some contexts. Urbanization drives nonrenewable energy demand but offers opportunities for renewable integration contingent on governance quality. Education enhances renewable energy consumption by fostering a skilled workforce and knowledge development. The findings suggest key policy implications. First, financial openness should be directed toward green finance and renewable energy investments. Second, trade policies must focus on reducing barriers to renewable technology imports and fostering global collaborations. Third, economic openness should prioritize sustainable FDI in clean energy sectors. Fourth, urban planning must incorporate decentralized energy systems and green technologies. Finally, investing in education and institutional reforms is essential to drive innovation and ensure effective governance. This study contributes to the discourse on energy transitions in BRI nations, emphasizing the critical role of openness and offering actionable policies to balance economic growth with sustainability.

Keywords: Energy Transition, Financial Openness, Trade Openness, Economic Openness, Renewable Energy, Belt and Road Initiative, SDG
JEL Classifications: Q43, F21, Q56; O44

1. BACKGROUND OF THE STUDY

The Belt and Road Initiative (BRI), launched by the People's Republic of China in 2013, has developed into a significant framework for promoting renewable energy advancement in various nations. This initiative seeks to improve global trade and foster economic collaboration while progressively incorporating sustainable energy projects into its agenda, signifying a notable shift in China's foreign investment strategy. This strategic transition to clean energy is in accordance with the global initiative for sustainable development and responds to pressing issues related to climate change and energy security, which are gaining heightened attention in current discourse. China, as the principal architect and driving force behind the Belt and Road Initiative, has recognized the crucial importance of renewable energy in mitigating the adverse effects of climate change. The Belt and Road Initiative functions as a strategic framework through which China can leverage its technological innovations and substantial financial capabilities to invest in renewable energy initiatives in various participating countries. In this context, China is establishing itself as a prominent leader in the global shift towards a more sustainable economy. The leadership role is further highlighted by China's pledge to attain carbon neutrality by 2060 and its proactive participation in international climate agreements, which underscores its commitment to sustainable development objectives (Li, 2023; Xiao et al., 2018).

The integration of renewable energy initiatives within the Belt and Road Initiative framework fulfils a variety of objectives. This document primarily addresses the urgent necessity for energy diversification in numerous Belt and Road Initiative (BRI) countries, especially those that exhibit a significant reliance on fossil fuels. Through investments in solar, wind, hydroelectric, and various other renewable energy sources, China is facilitating these nations in their efforts to decrease carbon emissions and improve energy security. The importance of diversification becomes particularly pronounced in the context of volatile global energy prices and the geopolitical tensions frequently associated with dependence on fossil fuels (Chai et al., 2020; Tian et al., 2019). Moreover, the emphasis of the Belt and Road Initiative on the advancement of renewable energy underscores a wider acknowledgement of the economic prospects associated with the shift towards a sustainable energy framework. Investments in renewable energy infrastructure serve a dual purpose: they generate employment opportunities and invigorate local economies by promoting innovation and drawing additional investments. The establishment of solar farms or wind energy projects has the potential to catalyze the development of ancillary industries, including manufacturing and maintenance services. This, in turn, can generate additional employment opportunities and enhance local economic resilience (Gao and Li, 2023; Liaqat et al., 2022).

The Belt and Road Initiative not only presents economic benefits but also prioritizes renewable energy, thereby enhancing international collaboration among the nations involved. Collaborative energy initiatives allow countries to exchange best practices, technological advancements, and policy frameworks that support the transition to renewable energy sources. The implementation of a cooperative approach is crucial for tackling the collective challenges presented by climate change and energy insecurity. This strategy facilitates the transfer of knowledge and the enhancement of capacities among nations that possess differing degrees of technological development and financial capabilities (Wei, 2019; Zhu, 2023). Furthermore, the Belt and Road Initiative's dedication to the advancement of renewable energy is in harmony with the United Nations Sustainable Development Goals, specifically Goal 7, which seeks to guarantee access to affordable, reliable, sustainable, and modern energy for all individuals. Through its investment in renewable energy initiatives, China plays a significant role in the global endeavour to meet these objectives, consequently bolstering its international reputation and influence. The alignment with the Sustainable Development Goals (SDGs) enhances China's reputation as a responsible participant in the global arena and facilitates opportunities for collaboration with other nations and international organizations that emphasize sustainable development (Iftikhar et al., 2024; Li, 2024).

Although these investments are frequently presented as a strategy to foster sustainable development, there are significant concerns related to the phenomenon of "greenwashing." This occurs when projects are advertised as environmentally friendly yet fail to provide meaningful environmental advantages. Furthermore, the financial sustainability of these initiatives represents a crucial factor, given that numerous countries involved in the Belt and Road Initiative may encounter debt burdens that could hinder their capacity to invest in and uphold renewable energy infrastructure (Cao et al., 2022; Teo et al., 2019; Tian et al., 2019). Moreover, the geopolitical aspects of the Belt and Road Initiative require careful consideration. The investments made by China in renewable energy can be interpreted as a strategic manoeuvre to enhance its influence within the countries involved. This situation prompts critical inquiries regarding issues of sovereignty and the potential risks associated with dependency on Chinese technology and financial resources. This dynamic requires a sophisticated comprehension of the interactions among economic development, environmental sustainability, and geopolitical strategy within the framework of the Belt and Road Initiative (Chan, 2018; Shichor, 2018). The transition to clean energy effectively responds to the pressing issues associated with climate change and energy security, simultaneously generating new economic prospects and promoting international collaboration. It is essential to conduct a thorough evaluation of the implications associated with these investments, ensuring that they genuinely foster sustainable development rather than merely acting as a veneer for geopolitical objectives. As the international community progresses through the intricacies of energy transition, the Belt and Road Initiative's influence on the future of renewable energy will certainly persist as a central theme in both academic and policy discussions (Cao, 2019; Sharifi and Khavarian-Garmsir, 2020).

The present study has considered openness, urbanization, education, financial development and domestic capital formation in the equation of energy transition in BRI countries.

In general, the findings of the literature suggest that there is a positive relationship between financial openness and energy consumption. That is, as countries become more open to international capital flows, they tend to consume more energy. The mechanisms through which this occurs are likely to vary depending on the country's context. In developed countries, for instance, it has been suggested that increased financial openness leads to higher levels of investment in energy-intensive industries. In contrast, in developing countries, increased financial openness may lead to higher levels of government expenditure on energy subsidies. There is also a large body of evidence suggesting that there is a positive relationship between trade openness and energy consumption. That is, as countries become more open to international trade, they tend to consume more energy. Again, the mechanisms through which this occurs are likely to vary depending on the country's context. In developed countries, for instance, it has been suggested that trade liberalization leads to increased imports of energy-intensive goods.

In the case of urbanization, which is taking over the world. With more and more people moving to cities, urban areas are becoming more populous and resource-intensive. This growth has huge implications when it comes to renewable energy resources and consumption. As the world's population continues to grow, so does the demand for energy. This increase in demand is largely driven by urbanization, as more and more people move into cities. In fact, it is estimated that by 2050, 66% of the world's population will live in urban areas. Urbanization has a number of effects on energy consumption, both good and bad. On the one hand, cities are more efficient places to live when it comes to energy use. For example, people in cities tend to use public transportation more than those in rural areas, which cuts down on emissions from individual vehicles. Additionally, high-density living makes it easier to heat and cool buildings efficiently. On the other hand, however, urbanization can also lead to increased energy consumption. For instance, as cities grow larger and more complex, they require more energy to run properly. Additionally, many people who move to cities are looking for a higher standard of living, which often requires more energy to maintain. Overall, urbanization is a major driver of energy consumption around the world. As cities continue to grow in size and population, it is important to consider both the positive and negative impacts of this trend on renewable energy sources.

The present study has considered openness in the equation of energy transition, particularly the intention to overview the potential effects of financial openness, trade openness, and economic openness on renewable energy, nonrenewable energy, and fossil energy consumption in BRI nations for the period 2004-2020.

This study makes significant contributions to the existing literature by addressing critical gaps in understanding the interplay between openness and energy consumption dynamics within Belt and Road Initiative (BRI) nations. While previous research has explored the individual roles of financial, trade, and economic openness on energy transitions, limited attention has been paid to the nuanced interdependencies and region-specific effects within the BRI framework. This study bridges this gap by providing a comprehensive, multi-dimensional analysis of openness and its impact on renewable, nonrenewable, and fossil energy consumption.

First, the study uniquely integrates advanced econometric techniques such as Cross-Sectionally Augmented Autoregressive Distributed Lag (CS-ARDL) and Nonlinear ARDL models to capture both symmetric and asymmetric effects of openness on energy consumption. This methodological rigour ensures a robust understanding of the long- and short-term dynamics, offering insights that extend beyond traditional linear frameworks. Second, the research incorporates urbanization, financial development, and education as control variables, providing a holistic perspective on how socio-economic factors influence energy transitions in the context of the BRI. This inclusion highlights the interlinkages between demographic trends, institutional quality, and energy policies, which have been underexplored in prior studies. Third, the study contributes to policy discourse by identifying specific channels through which financial, trade and economic openness can facilitate renewable energy adoption. For instance, the findings underscore the role of trade openness in technology transfer, economic openness in attracting green investments, and financial openness in mobilizing capital for renewable projects. Finally, by focusing on BRI nations, the study contextualizes energy transition within a strategic geopolitical framework, shedding light on how the BRI's infrastructure investments and collaborative networks influence sustainable development goals. This regional focus fills a critical gap in understanding the BRI's role as a catalyst for global energy transformation.

2. LITERATURE REVIEW

2.1. Financial Openness and Energy Consumption

Foreign investment can pave the way for groundbreaking technologies and resources, which in turn can unlock unprecedented access to energy sources. While financial openness can bring about numerous benefits, it can also result in heightened competition for valuable resources like oil and gas (Baek (2016), Gökmenoğlu and Taspinar (2016), Agrawal and Khan (2011). This, in turn, can cause prices to skyrocket and lead to a greater reliance on non-renewable sources, ultimately posing a significant challenge. When it comes to policies related to energy consumption, policymakers must strike a delicate balance between the advantages of financial openness and its possible downsides. Investing in renewable energy sources is crucial to reduce our dependence on non-renewables in the long run. Let us take action and make the shift towards a sustainable future. A study by Shahzad et al. (2017) found that a percentage increase in trade openness and financial development will increase carbon emissions by 0.247% and 0.165%, respectively.

Further evidence can be found in Mavikela and Khobai (2018), where the author mentioned an unidirectional causality between FDI and energy consumption. The study also revealed a positive relationship between these two variables. Similar findings can also be found in the study of Abdouli and Hammami (2017), where the author applied the GMM method and found that FDI inflows and energy consumption have a unidirectional causal relationship globally. Therefore, in both individual and collective nations, increasing energy consumption leads to increased FDI inflows. Another study by Hans and Choudhary (2019) suggested that if FDI contributes more to the GDP and overall economy, it can attract more FDI than if it contributes less. The study also found that FDI has also contributed significantly to the GDP of India as compared to China. Again, Agrawal and Khan (2011) applied the OLS method in a study based on India and China and concluded that foreign direct investment and GDP have a positive correlation. However, China, is more affected by FDI than India in this study.

The undeniable truth is that Foreign Direct Investment (FDI) is a catalyst for progress, bringing with it cutting-edge technology and vital infrastructure investments that inevitably lead to a surge in energy demand (Doğan et al., 2020; Hans and Choudhary, 2019; Wang and Jiayu, 2019). It is worth noting that financial openness can pave the way for wider acceptance of renewable energy sources by providing ample funding for research and development in this field. By implementing policies that encourage the use of clean energy technologies, we can draw in more foreign direct investment towards sustainable projects. This will lead to a significant reduction in carbon emissions and an overall improvement in environmental sustainability. The intricate connection between financial openness and energy consumption, both renewable and non-renewable, is undeniable. However, governments must strike a delicate balance between driving economic growth through foreign direct investments and prioritizing the reduction of carbon footprint by embracing green initiatives and ramping up the usage of renewable energy sources. Doytch and Narayan (2016) conducted a study based on 74 countries and stated that economic growth in low- and lower-middle-income countries influences renewable energy consumption when FDI is controlled. An empirical study by Baek (2016) exposed that CO2 emissions tend to increase with foreign direct investment, supporting the pollution haven hypothesis, but income and energy consumption have a detrimental effect on CO2 reduction. Similarly, Gökmenoğlu and Taspinar (2016) could not show any direct positive or negative impact of FDI and energy consumption, but the study found unidirectional causal relationships running from economic growth energy consumption to FDI and from economic growth to energy consumption. In case of European countries, Doğan et al. (2020) performed a study where the findings stated that FDI, trade openness, economic complexity, and institutional quality are all key factors promoting economic growth. According to a study base on Ghana by Wang and Jiayu (2019) proved that foreign direct investment and industry value-added positively correlate with energy consumption, whereas financial development and energy prices negatively correlate. According to Rafindadi et al. (2018), the result of the study discovered that FDI inflows are negatively affecting the environment, while energy consumption is positively affecting the environment, and both affect carbon emissions in the region in a statistically significant way. On the other hand, Wang and Jiayu (2019) applied ADF test to the study and found that FDI had negative scale effects, structural effects, and positive technical effects on energy consumption in Shandong province (China), but the total effect was negative. However, Based on Jiangsu Province (China), Abdouli and Hammami (2017) stated, in general, the effects of FDI structure and technology fluctuate and do not contribute to reducing energy consumption intensity. So, it basically has positive impact but to reduce it government should adopt unified energy-saving and emission-reducing technology. However, according to Salim et al. (2017), FDI reduces energy consumption by 0.21% in China.Although the study also found FDI and energy consumption are positively correlated in the short run. As a result, the study suggested that, in order to fully internalize FDI-related knowledge spillovers in energy conservation, the Chinese government should support inward FDI in tertiary and energy sectors.

2.2. Urbanization and Energy Consumption

One of the most significant implications of urbanization (as seen in the movement from rural areas to cities) is its effect on energy consumption patterns. In countries that are involved with the BRI, urbanization generally means rapid economic development and expansion of infrastructure. Urbanization typically happens in tandem with increased energy demand as a result, which is particularly evident in the BRI, with urbanization directly linked to both renewable and nonrenewable power consumption. Urbanization is found to increase energy consumption overall in the BRI countries, though it is also possible to demonstrate that specific types of renewable energy account for a relatively higher proportion of this new total (since both such types are unequally distributed). By this means, we can achieve better environmental protection and development in line with sustainable processes. (Dong and Pan, 2020; He et al., 2021; Zhao and Qamruzzaman, 2022)The BRI is a framework to further the development of renewable energy sources in countries in which it is active. It helps us all to move toward cleaner energy sources by doing this. This approximation of the goals of global development points up again to the contradiction of turning toward an industrial path that burns first money and then people and nature. The establishment of renewable energy infrastructure in the BRI has been given a boost through this initiative, whose thrust is from fossil fuels towards sustainable sources (Hussain et al., 2022). Moreover, urban areas must incorporate renewable energy into plans for expansion and modernization. Cities are the biggest consumers of energy and also account for a large proportion of air pollution. The potential use of renewable energy in urban areas remains abandoned and this calls for both innovative policies and financing methods which can support the decentralization of energy supply systems (Kusch-Brandt, 2019; Sait et al., 2018). In addition, the correlation between urbanization and renewable energy consumption is influenced by many factors apart from economic success, technological progress or individual acts; relevant support institutions and their operating efficiency will greatly affect the outcome.

Although urbanization promotes the use of clean energy in such places, it can also bring us into contact with both such effects as worsened air pollution and more frequent flash floods (Anwar et al., 2021; Sheraz et al., 2021). The positive relationship between renewable energy consumption and economic growth underscores the importance of incorporating renewable energy strategies into urban development plans. Alternatively, if you analyze the effects of urbanization on renewable energy consumption in another context, you will find a different picture. Urbanization in developing countries, for example, is expected to exacerbate nonrenewable energy consumption but have no impact whatsoever on renewable energy use (Salim and Shafiei, 2014). This difference in the effect of urbanization on energy consumption patterns in different regions and under different economic circumstances is worthy of our attention. Literature advocates that in developed countries, urbanization does not necessarily lead to a corresponding increase in the use of renewable energy, perhaps due to structures established to support non-renewable sources.

Similarly the role of governance and institutional frameworks in shaping the impact of urbanization on renewable energy consumption is crucial: good governance can promote the integration of renewable energy technologies in cities, making energy use more sustainable and reducing reliance on nonrenewable power sources (Gnangoin et al., 2023). If governance structures are strong within a region, there is a high probability of successful integration of renewable energy into urban planning. The outcome of such integration is to alleviate energy intensification and decrease greenhouse gas emissions more than otherwise (Kassi et al., 2021).

Conversely, in regions with lesser governance capacity the process by which to transition toward renewable energy is likely to be obstructed, bringing about a stalling of alternative development paths and more environmental pollution on account of increased coal/petrol burning. (Chin et al., 2022) Advocated that the economic impact is also considerable in the era of urbanization. When cities expand in land area, energy service demands surge along with them, requiring a transition to more sustainable forms of energy production. Urbanization also leads to increased investment in renewable energy infrastructure, particularly in the developing world, where energy is essential for moving up into the economic ranks. The potential for renewable energy to stimulate economic growth and, at the same time, relieve environmental stress is also an important part of urban sustainability strategies (Jia et al., 2021). Also the building of renewable energy technology systems in urban settings will make them more resilient in the face of any challenge, again particularly climate change. Urban areas are susceptible to the impacts of climate change now more than ever before; to build low-carbon cities, it is essential to take energy from renewable sources. Renewable energy technologies ease the impact of climate change by reducing the quantity of greenhouse gases emitted and pushing urban development in a sustainable direction. Summing up, the effects of urbanization on renewable energy consumption are both complex and contingent. There is a sharp contrast between BRI countries and the rest of the international community. BRI provides a unique opportunity to harness urbanization as an impetus for renewable energy development, yet it is not at all certain that Smokey City will make any such dependence upon Cleaner. One method would increase production if it were otherwise. The interaction of governance, economic factors and technical capabilities is vital to whether urbanization is a positive force for renewable energy consumption. As cities keep on growing, it will be crucial for them to incorporate renewable energy technology into their urban plans if they are also to achieve sustainable development goals and tackle the challenges of global warming.

2.3. Financial Development and Energy Consumption

Chiu and Lee (2020) Compared the impact of the stock market and banking sector on energy consumption. The outcome of the comparison revealed that development in the banking sector has a greater impact on energy consumption. Additionally, the results show that under stable country risk conditions, financial development might reduce energy consumption. However, Çoban and Topcu (2013) mentioned that energy consumption increases as financial development increases, regardless of whether it comes from the banking sector or the stock market. The analysis of Ma and Fu (2020) indicates that financial development has a positive effect on energy consumption in developing countries, whereas it does not make much difference to energy consumption in developed countries. The study also suggests that energy consumption and financial sector development must be balanced in developing countries. According to Islam et al. (2013), A significant reduction in energy use can be achieved by increasing energy efficiency through financial development. Moreover, to facilitate the development of its financial sector, Malaysia should take extra precautions to ensure the appropriate infrastructure and environment are in place. More evidence can be found in the study of Khan and Khilji (2011), where the author noted that, by improving energy efficiency, financial development can be useful in addressing energy issues in Pakistan even though the money supply is causing energy consumption.

Kakar (2016) conducted a study on both of these countries. Based on these results, it is apparent that energy consumption is essential to economic growth in both countries, and a sudden increase in energy prices may be detrimental to the convergence process. On the other hand, improvements in technology and a stronger capital market can improve energy consumption. More relatable outcomes can be found in the study of Danish and Ulucak (2021) and Komal and Abbas (2015), where the study confirms that energy consumption increases with urbanization, globalization, economic growth and financial development in Pakistan. Even based on GCC countries, Al-mulali and Lee (2013) conducted a study using the OLS method and found, in the long run, Financial Development, Urbanization, GDP, and Total Trade positively affect energy consumption.

In the case of Saudi Arabia, Mahalik et al. (2017) performed an analysis where the estimation indicates that energy demand will increase in the long-run as financial growth continues. Additionally, urbanization and capital are two of the key factors driving increased energy demand in the long run, while economic growth is inversely related to energy consumption. Further evidence can be found in the study of Shahbaz and Lean (2012), the results reveal a significant and positive association between energy consumption and financial development. Moreover, energy consumption and financial development exhibit long-run bidirectional causality. In the case of another oil-rich Economy Azerbaijan Mukhtarov et al. (2018) found that In the long run, financial development and economic growth have a positive and statistically significant impact on energy consumption. Following the study of Gaies et al. (2019), the result indicates that in MENA countries, the energy demand increases with financial development and then, at a turning point of financial development, it declines because of a non-linear U-shaped relationship.A similar result can be found in Baloch et al. (2019), where the outcome reveals that consumption of energy and financial development have an inverted U-shaped relationship.

This finding from Mukhtarov et al. (2020) shows a positive relation between financial development and energy consumption, where a 1% increase in financial development and economic growth increases energy consumption by 0.11 and 0.39%, respectively. Similar findings can be found in the study of Sadorsky (2011), where the author performed an empirical study based on 9 Central and Eastern European economies. The results of the dynamic panel demand models show a positive and statistically significant relationship between financial development and energy consumption. Empirical results from Sadorsky (2010) reveal a positive and statistically significant relationship between energy consumption and financial development. The study also stated that developing economies with steadily developing stock markets will see an increase in energy demand in addition to income increases. Again, Yue et al. (2019) performed a study based on 21 transitional countries and found that the development of financial intermediaries positively affected energy consumption. However, the development of stock markets in China and Poland led to a reduction in energy consumption. On the other hand, Results from Furuoka (2015) suggest that finance and energy consumption in the region are in long-run equilibrium. Additionally, this study found that economic development did not appear to increase energy consumption in Asia, but energy use was likely to lead to improvements in the financial sector.

2.4. Gross Capital Formation and Energy Consumption

Solarin (2011) conducted a study based on Botswana and found that in the long-run estimates, electricity consumption is positively correlated with real gross domestic product in the long run, supporting the Granger causality tests. The study also revealed that as a highly energy-dependent country, Botswana's capital formation is partly determined by adequate electricity, influencing the country's economic performance. Again, according to Narayan and Smyth (2008), a long-run relationship is found between capital formation, energy consumption, and real GDP, with capital formation and energy consumption Granger affecting real GDP positively. However, Topcu et al. (2020) could not identify any direct relationship between gross capital formation and energy consumption. However, the authors mentioned a unidirectional causality between these two variables. Furthermore, in a study based on Pakistan, Hassan et al. (2020) showed that the relationship between natural resources, GCF, energy consumption, urbanization, and GDP per capita appeared to be unidirectional. The study suggested that to support the business community, improve the use of natural resources, and improve Pakistan's economic flexibility, the government of Pakistan should impose policies pertaining to their proper use. Again, we can see similar findings in the study based on Balkan countries where the authors Mitić et al. (2020) found that CO2 emissions and industrial fixed capital formation both have unidirectional causalities. The result from Pugu (2021) suggested that electricity production and energy production in Indonesia are not affected by most measures of gross/fixed capital formation.

3. DATA AND METHODOLOGY OF THE STUDY

3.1. Theoretical Development and Model Specification

Empirical evidence suggests that there is a nexus between financial openness, trade openness, economic openness and energy consumption. Financial openness refers to the degree to which a country's financial sector is open to international capital flows. Trade openness measures the extent to which a country's economy is integrated into the global trading system. Economic openness captures the degree to which a country's economy is open to foreign trade and investment. Renewable energy sources include solar, wind, geothermal, biomass and hydro power. Non-renewable energy sources are fossil fuels such as coal, oil and natural gas. Fossil energy consumption refers to the total amount of energy consumed from all fossil fuel sources.

The empirical evidence suggests that countries with higher levels of financial openness, trade openness and economic openness tend to consume more renewable energy, non-renewable energy and fossil energy (Doğan et al. (2020), Hans and Choudhary (2019), Wang and Jiayu (2019), which suggests that there is a nexus between these three factors and energy consumption. There are several possible explanations for this nexus. First, countries that are more open to international capital flows tend to have higher levels of economic activity, which in turn leads to higher levels of energy consumption. Second, countries that are more integrated into the global trading system tend to have higher levels of trade and investment activity, which also leads to higher levels of energy consumption. Third, countries that are more open to foreign trade and investment tend to have more liberalized economies, which provides an incentive for firms operating.

In recent years, the relationship between economic growth and renewable energy usage has been the topic of much discussion. An important question is whether nations with more financial development are more inclined to invest in renewable energy technology or if the converse is true. An increasing amount of data demonstrates that financial development does have a favourable effect on investments in renewable energy. According to a number of studies, nations with more financial development are more inclined to invest in renewable energy technology. For instance, according to research by the International Energy Agency, nations with more developed banking sectors are more inclined to invest in renewable energy. Similarly, research conducted by the World Bank indicated that nations with better access to finance markets were more inclined to invest in renewable energy. According to the report, this is especially true for investments in wind and solar energy. There are many reasons why financial growth may increase renewable energy investments. First, financial development can offer the resources required to fund the initial investment expenses of renewables. Second, financial institutions can offer the knowledge required to discover and evaluate renewable energy investment prospects. Finally, financial markets may play a significant role in supporting the deployment of renewables by providing the means for corporations and governments to obtain cash for investment in renewables.

The generalized empirical model of the study is as follows:

$$EC_{REC,NREC,FFC} \int FO,TO,EO \quad (1)$$

Where REC, NREC, FEC, FO, TO, and EO denote Renewable energy consumption, nonrenewable energy consumption, Fossil energy consumption, financial openness, trade openness, and economic openness, respectively. Taking into account the existing literature, see, for instance, the above baseline equation (1) has extended with the inclusion of a set of three control variables that are gross capital formation (GCF), financial development (FD), and government expenditure on education (EDU), respectively. The revised Eq (1) with control variables are as follows in Eq (2).

$$EC_{REC,NREC,FFC} \int FO,TO,EO,GCF,FD,EDU \quad (2)$$

After transforming the natural log, equation (2) can be rewritten in the following regression equation in deriving the coefficients of independent and control variables. The transform equation with three different equations is as follows.

$$REC_t = \alpha_0 + TO_{it}\beta_t + FO_{it}\beta_t + EO_{it}\beta_t + FD_{it}\beta_t + EDU_{it}\beta_t + GCF_{it}\beta_t + \varepsilon_{it} \quad (3)$$

Equation (3) outlines the expected impacts of the independent variables on renewable energy consumption (REC). The positive impact of trade openness (TO), financial openness (FO), and economic openness (EO) on REC is anticipated. Enhanced trade openness facilitates the opportunity to tap into global markets, which can have a positive impact on the uptake of renewable energy, which is because it allows for greater ease in both exporting and importing renewable energy technology and products. Financial openness promotes the inflow of foreign investments, thereby providing additional funding for renewable energy projects. This, in turn, has a positive impact on the Renewable Energy Certificate (REC) market. The level of economic openness, which indicates how open an economy is to international trade and investment, can have a significant impact on policies that support the use of renewable energy, which, in turn, can have a positive effect on the Renewable Energy Certificate (REC) market. Increased investments in infrastructure and capital assets have the potential to contribute positively to REC by promoting the growth of renewable energy projects. Financial development can play a crucial role in promoting renewable energy ventures by providing better access to capital. Additionally, government expenditure on education can indirectly contribute to the growth of the renewable energy sector by nurturing a skilled workforce, which works in tandem to promote and facilitate the expansion of renewable energy consumption.

$$NGC_t = \alpha_0 + TO_{it}\beta_t + FO_{it}\beta_t + EO_{it}\beta_t + FD_{it}\beta_t + EDU_{it}\beta_t + GCF_{it}\beta_t + \varepsilon_{it} \quad (4)$$

It is anticipated that a rise in trade openness, financial openness, and economic openness will contribute to an increase in natural gas consumption. This suggests that a more open economic environment could lead to a higher demand for natural gas as an energy source. In addition, it is worth noting that a rise in financial development could have a positive effect on NGC, implying that a robust financial sector has the potential to facilitate investments in activities related to natural gas. In addition, it is expected that an increase in government spending on education will have a modestly positive impact on NGC, which could be attributed to the fact that a more educated workforce tends to engage in economic activities that rely on natural gas. Ultimately, a higher gross capital formation (GCF) is expected to increase NGC, which is because it signifies a greater investment in infrastructure and industrial activities, which frequently depend on natural gas. The collective effects observed suggest that various factors, such as economic openness, financial development, and education spending, contribute to the influence on natural gas consumption patterns.

$$FFC_t = \alpha_0 + TO_{it}\beta_t + FO_{it}\beta_t + EO_{it}\beta_t + FD_{it}\beta_t + EDU_{it}\beta_t + GCF_{it}\beta_t + \varepsilon_{it} \quad (5)$$

Financial openness, represented by FO, has the potential to result in higher FFC as it may attract more capital into industries related to fossil fuels. In a similar vein, an uptick in trade openness, as indicated by TO, could potentially enhance FFC by fostering increased global trade in fossil fuels. On the other hand, economic openness (EO), which signifies a more inclusive economic atmosphere, could potentially decrease FFC as it promotes diversification and a move away from excessive dependence on fossil fuels. In addition, the growth of financial development (FD) and the allocation of government funds towards education (EDU) are anticipated to play a role in moderating the impact on FFC. Increased financial development has the potential to promote investment in cleaner energy sources, resulting in a reduction in harmful emissions. Additionally, if governments allocate more funds towards education, individuals may make more environmentally conscious choices, leading to a decrease in the consumption of fossil fuels. Finally, gross capital formation (GCF) can have varying effects depending on its allocation. Increased investment in cleaner technologies is likely to decrease FFC, while higher investment in traditional fossil fuel infrastructure may increase it. The definition of research variables and possible data sources are displayed in Table 1.

Table 1: Variables definition and data sources

Variables	Notation	Definition	Sources	Sign
Renewable energy consumption	REC	Renewables per capita (kWh - equivalent)	Energy institute	
Nonrenewable energy consumption	NREC	Natural Gas per capita (kWh)	statistical review of	
Fossil energy consumption	FEC	Fossil fuels per capita (kWh)	world energy	
Trade openness	TO	Trade openness is measured as the sum of a country's exports and imports as a share of that country's GDP (in %)	Penn world table	
Economic openness	EO	Net inflows of foreign direct investment from foreign investors to the reporting economy		
Financial openness	FO	KAO open index		
Financial development	FD	Domestic credit to the private sector	OurWorldinData	
Urbanization	UR	Urban population (% of total population)	OurWorldinData	
Education	EDU	Total general government expenditure on education as a percentage of total government expenditure on all sectors	OurWorldinData	

EO: Economic openness, TO: Trade openness, FO: Financial openness, EDU: Expenditure on education, FD: Financial development

3.2. Estimation Strategies

Estimation strategies for panel data analysis are critical for understanding the intricate relationships among variables while addressing the challenges posed by cross-sectional and temporal dimensions. The first step involves conducting slope heterogeneity tests, which ascertain whether the assumption of homogeneity across cross-sectional units is valid. This foundational analysis is essential as it identifies the presence of diverse responses among entities, guiding the choice of subsequent econometric models. By recognizing individual variations, researchers can enhance model accuracy and avoid biased parameter estimates, as highlighted by Han and Zhou, who emphasize the importance of accounting for heterogeneity in their study of carbon performance in China (Han and Zhou, 2022).

Following the assessment of slope heterogeneity, the next stage is the cross-sectional dependency test. This test evaluates whether dependencies exist across units, which is particularly relevant in globalized contexts where economic shocks or policy changes can have widespread effects. Pesaran's methodology for testing cross-sectional dependence is widely recognized for its robustness, and its application ensures that the analysis reflects the interconnected nature of economic variables (Pesaran, 2014). For instance, Wang et al. utilized this approach to investigate the relationship between COVID-19 and geopolitical risks, demonstrating the importance of managing cross-sectional dependencies to avoid spurious results (Wang et al., 2020).

Unit root tests, specifically the Cross-Sectionally Augmented Dickey-Fuller (CADF) and Cross-Sectionally Augmented Im, Pesaran, and Shin (CIPS) tests, are employed to evaluate the stationarity of variables in the presence of cross-sectional dependencies. These tests are superior to traditional unit root tests as they incorporate both time-series properties and cross-sectional interconnections, providing a more robust assessment of data stationarity. As noted by Xu (2023), the CADF and CIPS tests effectively address the challenges posed by non-stationary data, ensuring that the econometric models yield valid conclusions. The importance of establishing stationarity cannot be overstated, as it is a prerequisite for reliable econometric analysis.

Once stationarity is confirmed, cointegration tests are conducted to assess long-term equilibrium relationships among variables. These tests are crucial for determining whether non-stationary variables share a common trend, which is vital for understanding enduring economic relationships. The Westerlund cointegration test, for example, is particularly effective in this context as it accounts for cross-sectional dependence, thereby enhancing the reliability of the findings (Rizwanullah, 2024). This step is essential for establishing the validity of long-term associations, which significantly enhances the explanatory power of econometric models.

The estimation of long-run and short-run coefficients is facilitated by the Cross-Sectional Autoregressive Distributed Lag (CS-ARDL) model, which captures dynamic interactions while considering cross-sectional dependencies. This model provides a comprehensive view of how variables respond to changes over time and across entities, facilitating policy-oriented insights. The application of the CS-ARDL model allows researchers to derive meaningful interpretations of both short-run and long-run dynamics, as demonstrated in studies examining the impact of various economic factors on environmental outcomes (Meo et al., 2020).

Nonlinear ARDL models further extend traditional frameworks by accommodating asymmetric adjustments in relationships (Shin et al., 2014). These models are particularly useful for capturing the potential for different responses to positive and negative changes, reflecting the complexities of real-world economic dynamics. The inclusion of nonlinearity enhances the model's relevance and applicability in various contexts, as evidenced by the findings of studies exploring the relationship between energy consumption and economic growth (Sheikh and Hassan, 2023).

Finally, the Dumitrescu-Hurlin (D-H) causality test is employed to evaluate causal relationships in panel data, allowing for heterogeneity in causal links across units. This test aids in distinguishing between explanatory and dependent variables, refining the understanding of underlying economic mechanisms. By identifying causality, researchers can better interpret the dynamics at play, as highlighted in the work of (Dumitrescu and Hurlin, 2012b), which emphasizes the advantages of their approach in heterogeneous panels.

4. ESTIMATION AND INTERPRETATION

4.1. Cross-sectional Dependency, Slop of Heterogeneity and Unit Root Test

Research variables properties have guided the empirical nexus assessment by the section of an appropriate econometric model. This study implemented CSD, SHT, and PURT in documenting the research units elementar characteristics. Table 2 exhibits the results of the CSD and SH tests. Referring to the test statistics derived from the CSD test revealed the rejection of the null hypothesis of cross-section independency. Alternatively, the study established cross-sectional dependency among the research units. Additionally, the heterogeneity properties have been exposed through the execution of the slope of homogeneity test.

The study implemented the second generation panel unit root test by implementing CIPS and CADF proposed by Pesaran. The results of PURT are displayed in Table 3. Acccordign to test statistics found from CIPS and CADF with a level and revealed all eh variables are nonstationary, while the first difference operator established stationary by rejection of the null hypothesis of stationary.

4.2. Long-run Panel Cointegration Test

Next, the study executed a panel cointegration test by following the framework proposed by in, assessing the long-run association between energy consumption, which is measured by renewable, fossil and bioas and the explanatory variables. Based on the diverse proxy for dependent variables, the study performed three cointegration models for long-run assessment. The results of long-run cointegration are exhibited in Table 4, consisting of three panels of output. The test statistics derived from the panel

Table 2: Results of CSD test and heterogeneity test

Variables	LM_{BP}	LM_{PS}	LM_{Adj_bp}	PS_{CD}	Δ	Adj. Δ
lnTEC	441.359***	16.441***	147.261***	36.933***	79.389***	130.202***
lnREC	168.96***	28.163***	125.746***	10.761***	49.769***	92.577***
lnFEC	187.42***	41.244***	150.336***	40.965***	49.632***	114.864***
lnFO	277.479***	45.319***	183.921***	51.756***	61.227***	154.559***
lnTO	288.585***	15.324***	173.538***	29.659***	36.209***	105.096***
lnFD	274.805***	43.264***	163.478***	5.897***	89.472***	141.992***
lnUR	193.536***	42.807***	170.408***	40.23***	29.736***	123.06***
lnGCF	362.823***	44.289***	167.439***	32.35***	32.172***	96.822***
lnEDU	229.866***	35.285***	159.983***	48.336***	56.071***	153.303***

EO: Economic openness, TO: Trade openness, FO: Financial openness, EDU: Expenditure on education, FD: Financial development, GCF: Gross capital formation

Table 3: Results of panel unit root test

Variables	CADF test statistic		CIPS test statistic		CADF test statistic		CIPS test statistic	
	For constant		For constant		For constant trend		For constant and trend	
	Level	First difference	Level	First difference	Level	First difference	Level	First difference
lnTEC	−2.081	−4.675***	−1.582	−3.44***	−2.468	−7.197***	−1.962	−3.745***
lnREC	−2.225	−4.442***	−2.454	−3.452***	−2.359	−7.833***	−2.42	−4.893***
lnFEC	−2.753	−5.59***	−1.206	−6.343***	−2.721	−2.608***	−1.184	−3.92***
lnFO	−1.792	−4.379***	−1.119	−5.891***	−1.472	−2.145***	−2.208	−5.464***
lnTO	−2.554	−6.703***	−1.392	−3.171***	−2.214	−4.979***	−1.093	−3.886***
lnFD	−2.02	−6.49***	−1.436	−2.409***	−2.957	−3.145***	−2.453	−3.75***
lnUR	−2.116	−3.975***	−1.801	−2.105***	−2.969	−7.763***	−1.499	−3.597***
lnGCF	−1.878	−7.019***	−1.654	−5.226***	−2.259	−5.86***	−1.712	−6.959***
lnEDU	−1.464	−3.846***	−2.55	−2.416***	−1.186	−3.725***	−2.601	−3.112***

CIPS: Cross-Sectionally Augmented Im, Pesaran, and Shin, CADF: Cross-Sectionally Augmented Dickey-Fuller, EO: Economic openness, TO: Trade openness, FO: Financial openness, EDU: Expenditure on education, FD: Financial development, GCF: Gross capital formation

Table 4: Results of panel cointegration test

Model	For TEC	For REC	For FEC
Panel – A: Error-correction based panel cointegration test			
Gt	−12.559***	−9.189***	−12.443***
Ga	−13.299***	−8.035***	−11.06***
Pt	−13.45***	−9.872***	−9.158***
Pa	−13.955***	−10.854***	−10.252***
Panel – B: Kao Residual panel cointegration test			
MDF	10.808***	15.417***	16.084***
DF	−5.119***	−10.033***	−9.008***
ADF	−0.958***	−4.752***	15.109***
UMDF	0.18***	4.66***	22.651***
UDF	−1.744***	−1.914***	−1.985***
Panel – C: Conventional panel cointegration test			
MDF	11.302***	8.098***	3.949***
PP	3.753***	13.186***	6.088***
ADF	9.055***	14.8***	10.399***

ADF: Augmented Dickey-Fuller

cointegration test were found statistically significant at a 1% level, indicating the rejection of the null hypothesis of no-cointegration, alternatively revealing a long-run association between explained and explanatory variables.

4.3. Long-run and Short-run Coefficient: CS-ARDL Estimation

The coefficients see Table 5, of financial openness have established positive and statistically significant linkage with REC (a coefficient of 0.1206), NGC (a coefficient of 0.0259) and FFC (a coefficient of 0.0455) in BRI nations. Study findings illustrate that financial openness augmented energy consumption by accelerating economic aggregation. However, the transitional effect of financial openness has revealed that there is a positive growth in renewable energy consumption. In terms of short-run elasticities, the same domain of linkage was established between financial openness and renewable energy consumption (a coefficient of 0.0365), nonrenewable energy consumption (a coefficient of 0.0961 and fossil energy consumption (a coefficient of 0.0766). Referring to coefficient magnitudes, in the short run, the demand for non-renewable and fossil fuel consumption is more prominent than energy produced through renewable sources.

The coefficients of trade openness have been exposed as contribution factors of renewable energy consumption (a coefficient of 0.1389), nonrenewable energy consumption (a coefficient of 0.136) and fossil fuel consumption (a coefficient of 00277) in the long run. Additionally, in the short-run, study the elasticities of TO foster renewable energy consumption (a coefficient of 0.0669), nonrenewable energy consumption (a coefficient of 0.0797), and fossil fuel consumption (a coefficient of 0.0164). Referring to the coefficients of TO on energy consumption, especially on renewable energy consumption, it is apparent that TO intensifies the energy development from renewable sources, which is a possible indication of energy transition from conventional to eco-friendly energy inclusion in the economy.

Economic openness measured by the presence of foreign ownership in the economy as a proxy of inflows of FDI has exposed positive and statistically significant for renewable energy consumption

Table 5: Results of cross-sectionally augmented autoregressive distributed lag estimation

Variables	REC			NREC			Fossil		
	Coefficient	t-statistic	SE	Coefficient	*t*-statistic	SE	Coefficient	*t*-statistic	SE
Panel – A: long-run coefficients									
lnFO	0.1206	0.0053	22.7547	0.0259	0.0071	3.6478	0.0455	0.0059	7.7118
lnTO	0.1389	0.0112	12.4017	0.136	0.0115	11.826	0.0227	0.0098	2.3163
lnEO	0.1353	0.0031	43.6451	0.0742	0.0045	16.4888	0.0366	0.0054	6.7777
lnFD	0.1109	0.0032	34.6562	0.1311	0.0117	11.2051	0.0838	0.0091	9.2087
lnUR	0.0848	0.0086	9.8604	0.1665	0.0074	22.5	0.0625	0.0117	5.3418
lnEDU	0.1617	0.0097	16.6701	0.0525	0.0091	5.7692	0.0182	0.0042	4.32142
c	0.0554	0.0064	8.6562	0.0737	0.0077	9.5714	0.1197	0.0032	37.4062
Panel – A: Short-run coefficients									
lnFO	0.0365***	0.0023	15.8695	0.0961***	0.0118	8.144	0.0766***	0.0112	6.8392
lnTO	0.0669***	0.0108	6.1944	0.0797***	0.0038	20.9736	0.0164***	0.0076	2.1578
lnEO	0.0361***	0.0074	4.8783	0.0455***	0.0089	5.1123	−0.0361***	0.0033	−10.9393
lnFD	0.0164**	0.0076	2.1578	0.0245**	0.0073	3.3561	0.0044	0.003	1.48
lnUR	0.0066	0.0059	1.11864	0.0968***	0.0106	9.132	0.0037**	0.0881	4.2386
lnEDU	0.0079	0.0077	1.03246	0.0432***	0.0082	5.2682	0.0049	0.0029	1.68965
CD test		0.022387			0.02324			0.02856	
Wooldridge test for autoco		0.299305			0.576661			0.353486	
Normality test		0.051863			0.779715			0.832735	
Ramsey reset test		0.636707			0.6703			0.213132	

EO: Economic openness, TO: Trade openness, FO: Financial openness, EDU: Expenditure on education, SE: Standard error

(a coefficient of 0.1353), NGC (a coefficient of 0.0742), and FFC (a coefficient of 00366) for the long run assessment. Furthermore, according to short-run magnitudes, renewable energy consumption (a coefficient of 0.0364) and NREC (a coefficient of 0.0455) has a positive tie to economic openness, while fossil fuel consumption is adversely connected (a coefficient of -0.0361).

As far as financial development led energy consumption nexus, the study explored a positive and statistically significant tie. Precisely, financial development prompts all sources of energy consumption. More exactly, a 10% growth in domestic credit in the private sector will boost renewable energy consumption by 1.109%, nonrenewable energy by 1.311% and fossil energy by 0.838%, respectively. In the short-run, the positive statistically significant linkage was exposed to renewable energy consumption (a coefficient of 0.0164) and nonrenewable energy consumption (a coefficient of 0.0245), whereas a statistically insignificant connection was revealed with fossil energy. Urbanization, in the long run, has fostered nonrenewable energy consumption (a coefficient of 0.1665) over renewable energy (a coefficient of 0.0848) and fossil energy (a coefficient of 0.0625). Moreover, the coefficient of urbanization explained the triggering factor for nonrenewable energy consumption (a coefficient of 0.0968) in comparison to renewable energy (a coefficient of 0.0066) and fossil energy (a coefficient of 0.0037). Study findings suggest that urbanization prompts renewable energy consumption in the long run, but the obvious effects can be traced to nonrenewable energy consumption.

The effects of education on energy has exposed positively connected, suggesting that overall energy consumption has increasesd with the higher level of education attainment in the economy. More precisely, a 10% increase in secondary school enrollment in the economy will possibly expedite renewable energy consumption by 1.617%, nonrenewable energy consumption by 0.525% and fossil fuel by 0.182%, respectively, in the long run. Additionally, in the short-run, the coefficient of education on nonrenewable energy consumption has been found positive and statistically significant (a coefficient of 0.0432); rest of the case, education becomes insignificant.

4.4. Long-run and Short-run Coefficient: Nonlinear-ARDL Estimation

Table 6 displayed the coefficient of positive and negative shocks in financial openness revealed positive statistical significance at a 1% level with renewable energy consumption $(FO^{+}_{LR} = 0.0671, FO^{-}_{LR} = 0.1406 : FO^{+}_{SR} = 0.02301, FO^{-}_{SR} = 0.0337)$ nonrenewable energy consumption $(FO^{+}_{LR} = 0.0842, FO^{-}_{LR} = 0.1019 : FO^{+}_{SR} = 0.0363, FO^{-}_{SR} = 0.0345)$ and fossil fuel consumption. $(FO^{+}_{LR} = 1210,\ FO^{+}_{LR} = 1113 : FO^{+}_{SR} =), FO^{+}_{SR} =)$ For the long run, a 10% positive (negative) innovation in financial openness will result from an increase (decrease) renewable energy consumption by 0.671% (1.406%), nonrenewable energy by 0.842% (1.019%) and fossil energy by 1.210% (1.113%).

The asymmetric coefficients of trade openness unveiled positively connected with energy consumption, in particular, due to a 10% positive and negative innovation in trade openness will mark the acceleration (degradation) of renewable energy consumption by 1.102% (1.404%), nonrenewable energy consumption by 0.699% (0.615%), and fossil energy consumption by 0.836% (0.758%), respectively. Furthermore, in the short run, the asymmetric coefficients of trade openness disclosed positive and statistical linkage to renewable energy consumption (TO^{+} = 0.0487, TO^{-} = 0.009), non-renewable energy (TO^{+} = 0.0203, TO^{-} = 0.0254), and fossil energy (TO^{+} = 0.0417, TO^{-} = 0.0243).

The study revealed a positive and statistically significant linkage between economic openness and energy consumption in BRI nations both in the long run and short run. In particular, a 1% positive (negative) shock in economic openness results in

Table 6: Results of nonlinear augmented autoregressive distributed lag estimation

Variables	REC			NREC			Fossil		
	Coefficient	SE	*t*-statistic	Coefficient	SE	*t*-statistic	Coefficient	SE	*t*-statistic
Panel – A: long-run asymmetric coefficients									
FO^{+}	0.0671**	0.0437	1.5354	0.0842	0.0593**	1.4198	0.1210***	0.0057	21.05263
FO^{-}	0.1406***	0.0261	5.4076	0.1019	0.0805*	1.2658	0.1113***	0.0087	12.7931
TO^{+}	0.1102	0.0273	4.0366	0.0615	0.035	1.7571	0.0836	0.0301	2.786667
TO^{-}	0.1404	0.0682	2.0586	0.0699	0.0252	2.7738	0.0758	0.0075	10.10667
EO^{+}	0.1034	0.0202	5.1188	0.0951	0.0421	2.2589	0.0906	0.0229	3.956332
EO^{-}	0.1384	0.032	4.325	0.0653	0.0426	1.5328	0.034	0.00813	4.18204
FD	0.085	0.0412	2.0631	0.0681	0.0577	1.1802	0.0673	0.0176	3.823864
UR	0.0703	0.0652	1.0782	0.0614	0.0842	0.7292	0.1173	0.0231	5.077922
EDU	0.0826	0.0793	1.0416	−0.0895	0.0316	−2.8322	0.0982	0.0065	15.10769
Panel – B: short-run asymmetric coefficients									
ΔFO^{+}	0.02301	0.00402	5.72139	0.0316	0.00277	11.40794	0.042	0.00432	9.722222
ΔFO^{-}	0.0337	0.00579	5.82038	0.011	0.00247	4.453441	0.0356	0.00671	5.305514
ΔTO^{+}	0.0487	0.0066	7.37879	0.0203	0.0063	3.222222	0.0417	0.00272	15.33088
ΔTO^{-}	0.009	0.00406	2.21675	0.0254	0.00596	4.261745	0.0243	0.00321	7.570093
$\Delta EO+$	0.0429	0.00597	7.18593	0.0112	0.00819	1.367521	−0.0004	0.00766	−0.05222
$\Delta EO-$	−0.0064	0.00742	−0.86253	0.0447	0.00774	5.775194	0.045	0.0085	5.294118
FD	0.0326	0.0084	3.88095	0.041	0.00476	8.613445	−0.0045	0.00308	−1.46104
UR	0.034	0.00268	12.6866	0.0469	0.00444	10.56306	0.0267	0.00255	10.47059
EDU	0.0458	0.00855	5.35673	0.0158	0.00558	2.831541	0.0347	0.00248	13.99194
CointEq (−1)	−0.4379	0.0029	−151	−0.4007	0.0114	−35.1491	−0.3614	0.0039	−92.6667

EDU: Expenditure on education, FD: Financial development, SE: Standard error, EO: Economic openness, TO: Trade openness, FO: Financial openness

acceleration (degradation) of renewable energy consumption by 0.1034% (0.1384%), nonrenewable energy consumption by 0.0951% (0.0653%), and fossil energy by 0.0906% (0.0341%). On the other hand, the short–run coefficients of economic openness have established positive and statistically significant linkage between positive shocks in EO and renewable energy consumption and negative shocks in EO and nonrenewable energy consumption.

Referring to the coefficients of control variables are urbanization (a coefficient of 0.0850), financial development (a coefficient of 0.0703) and education (a coefficient of 0.0826), have revealed positive and statistically significant linkage to renewable energy consumption; moreover, the case of nonrenewable energy consumption, the study disclosed financial development augment (a coefficient of 0.0681), but education has negative (a coefficient of -0.0985) effects on non-renewable energy consumption.

Table 7 displays the results of the long-run and short-run symmetry tests with the null hypothesis of symmetry. The test statistics derived from a standard Wald test have rejected the null hypothesis and alternatively established the asymmetric association between explanatory and explained variables both in the long run and short-run.

4.5. DH Causality Test: Symmetric and Asymmetric Association

For direction association, the study has implemented a D-H causality test following Dumitrescu and Hurlin (2012a) with symmetric and asymmetric shocks. The results of the D-H causality test with a symmetric environment are displayed in Table 8.

4.6. Robustness Test AMG and CCEMG

The present study has extended the empirical model estimation robustness, especially of the long-run coefficients by employing PGM and CCEMG. The results of the robustness test are displayed in Table 9.

Table 7: Results of long-run and short-run symmetry test

Test	REC	NREC	Fossil
FO^{+}_{LR}	9.015	10.308	10.748
FO^{+}_{SR}	10.786	3.085	2.606
TO^{+}_{LR}	5.705	11.085	6.835
TO^{+}_{SR}	8.019	3.838	3.827
EO^{+}_{LR}	2.664	12.344	11.195
EO^{+}_{SR}	7.208	2.578	11.179

5. DISCUSSION

As the Belt and Road Initiative (BRI) moves forward, its implementation creates both challenges and opportunities. One such opportunity comes in the form of renewable energy consumption and financial openness within the BRI countries. For many years, renewable energy has been a topic of great import for both individual nations as well as international organizations. As more nations come online under the BRI umbrella, it is important to consider how increased financial openness and renewable energy consumption can help to drive success within this new era of global growth. Referring to the coefficients derived from CS-ARDL estimation and nonlinear estimation, there is a positive and statistically significant association between financial openness and energy consumption, which is measured by renewable energy, nonrenewable energy and fossil fuel. Our study findings of financial openness prompt renewable energy consumption have been supported by the existing literature for instance (Koengkan et al., 2020); Qamruzzaman and Jianguo (2020). There are a number of factors to consider when it comes to financial openness and renewable energy consumption in BRI countries. For one, the cost of renewable energy is often much higher than that of fossil fuels, making it difficult for many countries to switch to renewables. Additionally, many countries lack the infrastructure and technical expertise needed to develop

Table 8: Results of the D-H causality test

Variable	REC	TO	FO	EO	FDI	EDU	FD
Panel A: Energy consumption measured by renewable sources							
REC		3.7523**	4.4782**	4.7715***	3.2731**	1.7226	1.8395
		3.955	4.72	5.0291	3.4498	1.8156	1.9388
TO	1.3071		2.3974*	3.5047**	3.5313**	3.4165**	3.8384**
	1.3777		2.5269	3.694	3.722	3.601	4.0457
FO	5.8841***	3.2295**		0.9776	1.5536	4.1849**	5.1434***
	6.2019	3.4039		1.0304	1.6375	4.4108	5.4212
EO	1.7502	5.9819***	3.8894**		3.916**	1.2996	2.1774*
	1.8447	6.3049	4.0995		4.1275	1.3698	2.295
FDI	4.6907**	1.9426*	4.6556**	2.3443*		3.3283**	1.5441
	4.944	2.0475	4.907	2.4709		3.5081	1.6274
EDU	2.5079*	1.8969	2.069*	1.7959	2.3039*		2.0828*
	2.6434	1.9993	2.1808	1.8929	2.4283		2.1953
FD	5.5409***	6.1434***	2.154*	3.899**	1.8586	3.8097**	
	5.8401	6.4752	2.2704	4.1095	1.959	4.0155	
Panel B: Energy consumption measured by fossil fuel sources							
FFC		6.1859***	4.3294**	4.8299***	1.6673	3.3783**	2.6673*
		6.52	4.5632	5.0907	1.7574	3.5607	2.8114
TO	5.5664***		4.678**	1.8597	3.1115**	5.3464***	3.6099**
	5.867		4.9306	1.9601	3.2796	5.6351	3.8049
FO	1.1041	4.4325**		3.069**	5.9957***	6.2539***	4.119**
	1.1637	4.6718		3.2348	6.3195	6.5917	4.3414
EO	5.0031***	4.4187**	6.1636***		2.6992*	1.527	3.1147**
	5.2733	4.6573	6.4964		2.845	1.6095	3.2829
FDI	2.4091*	1.4335	3.3761**	3.6705**		2.5993*	2.1466*
	2.5392	1.5109	3.5585	3.8687		2.7397	2.2625
EDU	4.7927***	3.306**	5.4941***	5.1594***	4.2731**		4.9596***
	5.0515	3.4845	5.7908	5.438	4.5038		5.2274
FD	3.034**	4.8735***	3.5759**	0.8214	2.3103*	1.6333	
	3.1978	5.1367	3.769	0.8658	2.435	1.7215	
Panel C: Energy consumption measured by non-renewable sources natural gas consumption							
NREC		3.5781**	1.6174	4.6578**	3.0499**	1.5154	5.7513***
		3.7713	1.7047	4.9093	3.2146	1.5972	6.0619
TO	2.848**		1.7693	3.4548**	6.0127***	6.1859***	1.052
	3.0018		1.8649	3.6413	6.3374	6.52	1.1088
FO	3.2646**	6.018***		2.2252*	1.1402	3.1339**	3.7385**
	3.4409	6.343		2.3454	1.2018	3.3031	3.9404
EO	2.5866*	4.9755***	2.6014*		6.255***	2.6269*	1.7672
	2.7262	5.2442	2.7419		6.5928	2.7688	1.8627
FDI	3.6184**	1.7226	5.9319***	3.069**		1.8682	4.086**
	3.8138	1.8156	6.2523	3.2348		1.9691	4.3067
EDU	3.6259**	4.7523***	4.7205**	5.4303***	2.7619*		1.0042
	3.8217	5.009	4.9754	5.7236	2.9111		1.0584
FD	2.0265*	1.7428	1.4643	5.1753***	4.1424**	5.7566***	
	2.136	1.8369	1.5434	5.4548	4.366	6.0675	

EO: Economic openness, TO: Trade openness, FO: Financial openness, EDU: Expenditure on education, FD: Financial development, FDI: Foreign direct investment

and implement renewable energy sources. Another challenge is that many BRI countries are also members of the Organization of the Petroleum Exporting Countries (OPEC), which has been traditionally reluctant to embrace renewables. OPEC members are generally highly dependent on oil revenues, and so any shift away from oil would likely have significant economic impacts. Finally, it is worth noting that China, as the largest investor in BRI projects, has been increasingly vocal about its desire for greater financial transparency from project partners. This push for transparency may help to address some of the concerns around financial openness and could pave the way for more rapid adoption of renewables in BRI countries.

Trade openness fosters the growth of renewable energy consumption, which is in line with existing literature such as (Ibrahiem and Hanafy, 2021) but a contrasting finding published by (Zhao et al., 2020) for China. Referring to the nexus between trade openness and nonrenewable energy has unveiled a positive connection, suggesting the acceleration of nonrenewable sources, which is supported by the study of Zhao et al. (2020). Research indicates that trade openness significantly influences energy consumption patterns, with renewable energy sources being more sensitive to fluctuations in trade policies compared to conventional energy sources. For instance, studies have shown that as countries increase their international trade, there is a notable rise in renewable energy consumption, while the consumption of fossil fuels and natural gas exhibits less responsiveness to such changes (Arif et al., 2017; Kassi et al., 2021; Murshed, 2018). The increased sensitivity of renewable energy consumption to trade openness can be attributed to several factors. One key aspect is the enhanced access to renewable energy technologies and resources that comes with greater

Table 9: Results of robustness test: PGM and CCEMG

PGM				CCEEM			
Variables	Coefficient	t-statistic	SE	Variables	Coefficient	t-statistic	SE
Panel A: Energy consumption measured by renewable sources							
FO	0.089	0.0021	42.3809	FO	0.047	0.0087	5.4022
TO	0.0347	0.0075	4.6266	TO	0.0658	0.0117	5.6239
EO	0.015	0.0059	2.5423	EO	0.065	0.004	16.25
FD	0.0894	0.0096	9.3125	FD	0.0799	0.0105	7.6095
UR	0.0289	0.0115	2.513	UR	0.0515	0.0045	11.4444
EDU	0.0671	0.0056	11.9821	EDU	0.0541	0.0027	20.037
C	0.1069	0.0033	32.3939	C	0.0177	0.0108	1.6388
Wald test		0.0091		Wald test		0.0037	
CD test		0.0039		CD test		0.0079	
Panel B: Energy consumption measured by fossil fuel sources							
FO	0.1011	0.0042	24.0714	FO	0.0466	0.0102	4.5686
TO	0.0264	0.0079	3.3417	TO	0.0422	0.0108	3.9074
EO	0.0469	0.0082	5.7195	EO	0.0571	0.0064	8.9218
FD	0.0648	0.0083	7.8072	FD	0.052	0.0058	8.9655
UR	0.0159	0.0119	1.3361	UR	0.099	0.0086	11.5116
EDU	−0.1095	0.0098	−11.1734	EDU	−0.0926	0.0059	−15.6949
C	0.038	0.0077	4.935	C	0.0482	0.0071	6.7887
Wald test		0.0096		Wald test		0.003	
Panel C: Energy consumption measured by natural gas consumption							
FO	0.0137	0.006	2.2833	FO	0.0219	0.0099	2.2121
TO	0.0415	0.0035	11.8571	TO	0.0505	0.0051	9.9019
EO	0.0337	0.0089	3.7865	EO	0.0241	0.0051	4.7254
FD	0.0343	0.0048	7.1458	FD	0.0748	0.0039	19.1794
UR	0.0266	0.0042	6.3333	UR	0.0443	0.0058	7.6379
EDU	0.0986	0.009	10.9555	EDU	0.1004	0.0038	26.421
C	0.1118	0.0028	39.9285	C	0.0626	0.0032	19.5625
Wald test		0.0056		Wald test		0.0031	
CD test		0.0074		CD test		0.0064	

SE: Standard deviation, EO: Economic openness, TO: Trade openness, FO: Financial openness, EDU: Expenditure on education

trade liberalization. As countries engage more in international commerce, they often gain access to a wider array of renewable energy options, which can lead to increased implementation of renewable energy projects. For example, Murshed (2018) found that countries with diverse renewable energy choices are more likely to experience an uptick in renewable energy consumption, highlighting the importance of trade in facilitating technology transfer and resource availability. Furthermore, trade openness can stimulate foreign direct investment (FDI) in renewable energy projects, thereby enhancing a country's energy portfolio. Guz et al. (2023) emphasize that nations engaged in international trade are typically better positioned to attract investments in renewable energy, which can further bolster their energy consumption patterns (Yin and Qamruzzaman, 2024). The competitive market environment fostered by trade liberalization also plays a crucial role; as more providers enter the market, the cost of renewable energy technologies tends to decrease, making them more accessible to both businesses and consumers (Murshed, 2018). This competitive dynamic is essential for promoting the adoption of renewable energy sources and reducing reliance on fossil fuels.

In contrast, the consumption of natural gas and fossil fuels appears to be less affected by trade openness. This disparity may stem from the established infrastructure and supply chains associated with these energy sources, which are less susceptible to changes in trade regulations (Siddika and Ahmad, 2022; Wei, 2019). The fossil fuel industry, being more mature and entrenched, exhibits steadier consumption patterns that are not as influenced by fluctuations in international trade compared to the relatively nascent renewable energy sector. (Salim and Shafiei, 2014) Note that the established nature of fossil fuel markets contributes to their resilience against trade policy changes, resulting in less variability in consumption patterns. The findings underscore the critical role of trade openness in shaping energy consumption patterns, particularly in promoting renewable energy use. Policymakers aiming to enhance renewable energy consumption should consider the implications of trade policies on energy dynamics. By fostering international cooperation and trade, countries can facilitate the transfer of renewable energy technologies, attract investment, and create competitive markets that support the growth of renewable energy (Alam and Murad, 2020; Arif et al., 2017; Baker et al., 2014; Qamruzzaman and Kor, 2024).

Economic openness is measured by inflows of FDI in the economy, and the study disclosed aggregated energy consumption has swelled with the foreign capital adequacy that is both renewable and non-renewable energy sources; however, the coefficient is more obvious for fossil fuel than renewable energy consumption. The existing literature of (Doytch and Narayan, 2016; Shahbaz et al., 2022; Paramati et al., 2016). The research results show that foreign direct investment (FDI) has a significant influence on energy consumption trends, with a greater impact on fossil fuels compared to the use of renewable energy. This trend is even more pronounced in developing economies, as foreign direct investment (FDI) is often associated with increased energy consumption development and industrialization (Sharifi and Khavarian-Garmsir, 2020; Sheraz et al., 2021) also found that e-learning increases e-learning tool usage in their education system. It is positively correlated with fossil fuel consumption and FDI inflows. Specifically, it indicates that the influx of foreign capital in an economy is positively related to its overdependence on fossil fuels, thereby possibly leading to environmental degradation, which is in line with the pollution haven hypothesis, which states that the landmark works of a nation generally attracts more foreign direct investment (FDI) in a country with a lower degree of development and therefore results in higher emissions and higher energy consumption in non-renewable forms (Baek, 2017) Additionally, the relationship between foreign direct investment and energy consumption is said to differ; it varies significantly across different economic contexts and energy types. While fossil fuel investment from foreign direct investment has increased, so has associated consumption by renewable energy, so much so that its impact is not felt. This may result in overlooking sustainable energy investments and over-actuator economic interests (Elheddad et al., 2022; Kor, 2023). Moreover, there is prior evidence that the economic benefits of foreign direct investment most often also come with an increased demand for energy and degradation of environmental sustainability (Ali et al., 2020). Pointed out that the consumption of fossil fuels is a dominant factor in CO2 emissions in developing countries, where FDI is often assigned to energy-intensive industries. The trend raises serious issues about the long-term viability of fossil-fuel-based economic growth, which will create lasting environmental problems.

In contrast, some research suggests that a more balanced approach to foreign direct investment is necessary, incentivizing investments in renewable energy. According to Kutan et al. (2017); Murshed (2018), there is evidence that foreign direct investment in the renewable energy sector can reduce the adverse effect of fossil fuel usage and support sustainable development. Murshed et al. argue that the transition to renewable energy sources is needed to reduce ecological footprints without sacrificing economic growth. These approaches are consistent with the position held by Kibria et al., who emphasize the importance of policies aimed at encouraging foreign direct investment in cleaner technologies for achieving sustainable economic development (Kibria et al., 2019). As a result, a direct relationship between foreign direct investment inflow towards a country and increasing energy consumption, particularly from fossil fuels, is established. However, there is a broader realization of the need to invest in alternative sources of energy. The transition is key to achieving sustainable economic development while minimizing environmental impact. Encouraging foreign direct investment while supporting renewable energy initiatives must be embraced by politicians when creating a balanced energy future.

For financial development, the study divulged a positive tie to overall energy consumption in BRI nations, suggesting financial development amplifies the energy demand through personal channels and business channels. Our study is in line with existing literature such as. The possible motivation for excess energy demand in the economy is due to credit accessibility, lower lending cost and investment opportunity, indicating that financial development offers wealth effects for society and income effects for the individual, which largely increases energy consumption (Sadorsky, 2011; Zafar et al., 2020). The availability of more money is a direct result of economic expansion, which in turn raises demand for costly goods and drives up energy use. Moreover, Siddika and Ahmad (2022) identifies three ways in which a country's economic development affects its energy consumption: the direct influence, the business effect, and the wealth effect. More disposable income and credit opportunities lead to higher energy consumption because consumers can afford to buy more durable goods. Businesses and the economy as a whole gain from increased access to financial capital that is made possible by financial development. Consumer spending and economic growth both benefit from increased confidence in the economy. The expansion of the banking system spurs increased thrift, borrowing, and investment. Customers are more willing to invest in big-ticket items like refrigerators and washing machines when borrowing rates are low, leading to higher power use.

The effects of urbanisation on energy consumption have been revealed to be positive and statistically significant, especially in the long run, suggesting that people in urban areas have significantly better access to modern conveniences, including reliable power grids, fast and reliable internet connections, and clean drinking water. Urbanization is the movement from rural regions, whose economies are based on agriculture, to urban areas, which contain industrial and service sectors. This phenomenon is dynamic and moderates social and economic potential. Urbanization amplifies the energy demand through agricultural development with the integration of modern technology (Kalnay and Cai, 2003), technological innovation (Hemmati, 2006) and industrialisation (York, 2007). Urbanization is capable of shaping the economic patterns of resource use and global environmental quality, especially when paired with high urban densities. In a nutshell, the majority of developing countries are now undergoing economic change via urbanization. These nations have a high energy consumption potential and will contribute to a progressive decline.

6. CONCLUSION AND SUGGESTIONS

The study highlights the intricate relationships between financial openness, trade openness, economic openness, urbanization, financial development, education, and energy consumption within the Belt and Road Initiative (BRI) nations. The findings underscore that financial openness positively impacts the consumption of renewable, nonrenewable, and fossil energy, facilitating economic aggregation and renewable energy transitions. Trade openness similarly promotes renewable energy usage, suggesting an energy shift from conventional to sustainable sources. Economic openness, tied to foreign direct investment, reveals dual impacts: fostering renewable energy adoption while potentially sustaining fossil fuel dependence in the short run. Urbanization drives higher nonrenewable energy demand but also incrementally supports renewable sources, contingent on governance and infrastructural efficiency. Education emerges as a critical enabler, enhancing renewable energy consumption through knowledge development and workforce skill enhancement. Collectively, these factors reveal a nuanced energy transition pathway within BRI nations, shaped by economic integration, financial policies, and urban dynamics. The study's findings contribute to understanding the energy transition complexities and underline the importance of tailored policies to balance growth with sustainability.

Based on the study findings, the following policy suggestions have been formulated the foster the future energy transition with clean energy in BRI nations.

First, BRI nations should implement policies to attract foreign investments specifically targeted at renewable energy projects. Financial openness can serve as a channel to mobilize capital for infrastructure development, research, and innovation in clean energy. Establishing green finance frameworks, such as tax incentives for green bonds and renewable energy investments, will ensure that foreign capital directly supports sustainability goals. Additionally, fostering transparent financial systems can encourage greater international cooperation and confidence in renewable energy projects within BRI.

Second, Trade openness should be strategically directed to enable the import and export of advanced renewable energy technologies and expertise. This can be achieved through reducing tariffs on renewable energy equipment, negotiating trade agreements with technology-exporting countries, and promoting collaborations between local industries and global renewable energy firms. Such measures can lower the cost of adopting renewables and ensure technology accessibility, enabling BRI countries to accelerate their clean energy transitions.

Third, Economic openness, particularly through foreign direct investment (FDI), must prioritize renewable energy sectors. BRI nations should create incentives for foreign investors to channel funds into renewable energy infrastructure rather than fossil fuels. Governments can establish policy frameworks requiring a portion of FDI to be allocated to green projects or integrate sustainability performance metrics into FDI agreements. These measures can redirect economic openness as a driver for cleaner energy pathways.

Fourth, Urbanization, a significant factor in nonrenewable energy consumption, must be addressed through urban planning that incorporates renewable energy technologies. Policies should encourage smart city initiatives, the development of decentralized energy systems, and investments in energy-efficient infrastructure. Renewable energy integration in urban areas can be supported by subsidies for solar rooftops, public-private partnerships in wind and biomass projects, and mandates for green building standards.

Fifth, Investing in education as a channel for clean energy transition is vital. Governments should increase spending on renewable energy education, vocational training, and research programs. Collaborating with universities and private sectors to establish renewable energy research hubs and skill-building centers will ensure a trained workforce capable of driving innovation and adoption of renewable technologies.

Sixth, Effective governance structures are critical to channeling the benefits of openness and urbanization toward renewable energy. BRI nations should enhance institutional capacity to implement, monitor, and enforce renewable energy policies. Establishing independent regulatory bodies to oversee energy projects, ensuring compliance with environmental standards, and fostering regional cooperation among BRI countries for shared best practices can further strengthen governance.

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