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Research Article

The impact of external debt, remittances, political stability, and urbanization on renewable energy consumption in BIMSTEC nations: Evidence from DCE and DCE-IV estimation

Md. Qamruzzaman*

School of Business and Economics, United International University, Dhaka, Bangladesh.

Abstract. This study delves into the intricate relationships among external debt, remittances, political stability, urbanization, and renewable energy consumption in the context of BIMSTEC nations for 1995-2021. Motivated by the growing significance of sustainable energy practices and the need for informed policy decisions. This research employs a comprehensive methodology, including recently introduced Cross-sectional dependency, Slope of heterogeneity test, error correction-based cointegration test, Dynamic Common Correlated Effects (DCE), and instrumental variable-adjusted DCE method. While external debt shows a positive association with renewable energy consumption, careful consideration is required, as indicated by the nuanced impact of the DCE and Instrumental Variable (DCE-IV) models. Remittances exhibit a positive nexus with renewable energy consumption, emphasizing the role of household purchasing power. Urbanization, reflecting a positive correlation with unemployment rates, surprisingly points towards an increased demand for renewable energy, highlighting the need for strategic planning. Political stability, trade openness, and foreign direct investment (FDI) also demonstrate varying impacts on renewable energy consumption. The findings underscore the intricate nature of these relationships, urging policymakers to adopt tailored approaches. Consequently, this study contributes valuable policy insights for BIMSTEC nations, emphasizing the importance of sustainable energy strategies aligned with economic and social dynamics.

Keywords: Renewable energy consumption; External debt; Remittances, BIMSTEC

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1. Introduction

The Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation (BIMSTEC) nations stand at a pivotal socio-economic development. This group, constituting Bangladesh, India, Myanmar, Sri Lanka, Nepal, and Bhutan, represents diverse economies, cultures, and developmental trajectories within the dynamic Bay of Bengal region. Amidst their progress and challenges, this research explores the intricate interplay between five key factors—external debt, remittances, political stability, urbanization, and renewable energy consumption—disclosing their relationships and implications for policy formulation. The BIMSTEC nations have a significant economic influence due to their growing market and potential for growth and development. Their strategic location on major trade routes increases their importance in commerce, trade, and investment (Azam *et al.,* e2016; Star, 2023). All member nations have signed the BIMSTEC Free Trade Area Framework Agreement to strengthen trade, investment, and cultural ties. In addition, the BIMSTEC region has abundant natural resources and a variety of ecosystems, which offer possibilities for sustainable growth and cooperation in sectors like renewable energy, agriculture, fisheries, and environmental protection. Using this potential to REC advantage, the member countries strive to promote technological advancement, economic unity, and improved connectivity across borders to propel regional prosperity (Debates, 2021).

The importance of BIMSTEC goes beyond economic measures. It represents a joint effort among member states to tackle common issues like climate change, poverty, and socio-economic inequalities. The BIMSTEC nations aim to achieve inclusive development, promote cooperation, and ensure stability in the Bay of Bengal region through collaboration and knowledge-sharing (Ghosh, 2018; Ntanos *et al.,* 2018). Collectively, BIMSTEC member countries have made notable progress in renewable energy capabilities. India is leading the International Solar Alliance (ISA) to encourage the use of solar energy and share technology with member countries. The ISA's goal is to attract more than one trillion dollars in investment for solar energy by 2030. This initiative is a part of the more significant efforts in the BIMSTEC framework to improve and broaden power grid interconnections among member countries. It aims to establish transmission lines, upgrades, and cross-border connections to facilitate enhanced energy trade and cooperation (AMIR, 2023). The commitment to promoting renewable energy adoption and technology transfer is evident in the collaborative initiatives and investment efforts within BIMSTEC. This dedication can bring significant advantages to

* Corresponding author(s)
Email: qamruzzaman@bus.uiu.ac.bd (Md. Qamruzzaman)

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both the region and the globe. The continued collaboration in the oil and gas sector and the exploration of new energy routes demonstrate that the region is ready for long-term growth. BIMSTEC member nations are working towards reducing carbon emissions and encouraging renewable energy adoption; BIMSTEC bloc countries align with global environmental goals (Kant, 2022).

Several economic, political, and environmental determinants influence renewable energy consumption. For instance, Wealthier individuals tend to consume more renewable energy due to their ability to invest in renewable energy technologies and infrastructure (Polcyn *et al.,* 2022). Also, higher-income levels lead to increased renewable energy consumption as individuals can allocate more resources toward renewable energy sources (Ayodele *et al.,* 2021). Higher education can boost awareness of renewable energy benefits and encourage the adoption of renewable energy technologies (Mosly & Makki, 2018). The presence of jobs in renewable energy industries can impact the acceptance and use of renewable energy technologies. People who have worked in these industries are more inclined to embrace and adopt renewable energy technologies (Wang *et al.,* 2020). Regarding the political aspect, a study by (Chen *et al.,* 2021) gathered data from 97 countries from 1995 to 2015. It stated that democratic institutions could impact the adoption of renewable energy technologies by promoting favorable policies and regulations encouraging renewable energy development. What is more? Transparent institutions can ensure that renewable energy projects are carried out efficiently and with minimal corruption (Filimonova *et al.,* 2020). Besides, the level of concern about environmental problems can influence the use of renewable energy technologies. People more conscious of the environmental effects of using energy are more likely to choose renewable energy sources (Jaciow *et al.,* 2022).

Renewable energy consumption can also be attributed to various other contributing factors. In particular, the rate of technological advances can affect how quickly renewable energy technologies are adopted. When more advanced technologies are developed, they can make renewable energy systems more efficient and cost-effective (Oluoch *et al.,* 2021). Likewise, countries with open trade policies are likelier to adopt renewable energy technologies because they have better access to international markets and technologies. (Chen *et al.,* 2021). Last but equally significant, the growth of the population can impact the advancement of renewable energy. As the population increases, the energy demand also rises, encouraging the use of renewable energy sources (Yadav *et al.,* 2020).

Several studies have found a connection between *external debt* and increased environmental problems, specifically CO2 emissions, which implies that countries with significant levels of external debt may face difficulties in reducing their environmental impact, including promoting the use of renewable energy (Jianhua, 2022). A bidirectional causal relationship also exists between external debt, economic growth, CO2 emissions, and renewable energy consumption; external debt can impact renewable energy consumption and vice versa. High external debt can negatively impact a country's income, reducing renewable energy investment. (Akam *et al.,* 2021). In Turkey, high external debt can negatively impact a country's income, reducing renewable energy consumption (Saleem Jabari *et al.,* 2022). However, governments with limited access to traditional grants or debt relief can benefit from innovative debt swaps. These swaps can help them allocate more financial resources towards climate and nature-related projects. By doing so, it is possible to promote the use of renewable energy in developing countries (Kristalina Georgieva, 2022). Research has shown a connection between external debt and higher environmental problems, like increased CO2 emissions, in heavily indebted impoverished countries, which implies that countries with large amounts of external debt may need help reducing their environmental impact, including encouraging investment in renewable investment (Jianhua, 2022). Numerous studies have examined the influence of *remittances* on the use of renewable energy in developing countries. Governments can establish programs that encourage households receiving remittances to adopt and use energy devices that are more environmentally friendly. These programs offer lower costs for such devices if they pay with remittances (Karmaker *et al.,* 2023). Empirical findings also reveal that remittances positively influence renewable energy consumption, indicating that remittances can potentially improve renewable energy (Subramaniam *et al.,* 2023). One study discovered that increased remittances are associated with decreased renewable energy consumption (Seury *et al.,* 2023). Remittance inflows to developing countries have increased, leading to higher demand for renewable energy. This increased demand can result in more people adopting renewable energy technologies, lowering the cost of renewable energy projects. Additionally, remittances can fund renewable energy projects in developing countries. Political stability affects financial development, which can then affect renewable energy consumption. A stable political environment encourages financial growth, attracts investment in renewable energy projects, and promotes their development (Muoneke et al., 2023). Urbanization also significantly influences the consumption of renewable energy for several reasons. Urbanization drives the need for more energy, including renewable sources. As more people migrate to cities, electricity, heating, and cooling demand rises, resulting in higher renewable energy consumption. Additionally, urbanization leads to gathering people, resources, and knowledge, which helps use energy more efficiently, increase productivity, and advance technology. It also allows for adopting new technologies that can improve energy exploration and development and increase the use of renewable energy. Urbanization affects energy consumption and efficiency. It can result in higher energy usage but also promotes adopting renewable energy, which helps create a more sustainable energy mix (Sheng *et al.,* 2017).

By looking at the interrelations among foreign debt, remittances, political stability, urbanization, and renewable energy usage within the BIMSTEC countries from 1995–2021, this research greatly increases the body of knowledge already in use. Its contributions are listed below: First, this study clarifies the special difficulties and possibilities these BIMSTEC countries have in matching economic development with environmental sustainability by concentrating on them—a region strategically positioned but underused in sustainable energy transitions. Second, this study more reliably tackles cross-sectional dependencies and heterogeneity using the Dynamic Common Correlated Effects (DCE) and its instrumental variable-adjusted version (DCE-IV) than conventional techniques. These sophisticated econometric instruments expose correlations that past research would not have been able to capture completely. Third, the study shows that using renewable energy benefits from foreign debt, remittances, urbanization, political stability, and urbanization. It emphasizes doable policy recommendations such as using remittances for projects including clean energy and debt management to support environmentally friendly enterprises. Further, while earlier studies mostly concentrate on economic and environmental factors, this study integrates political stability and urbanization as fundamental determinants of renewable energy consumption, offering a larger framework for understanding the socio-economic dynamics influencing energy transitions. Finally, this study advances a complete knowledge of renewable energy dynamics in the BIMSTEC area by tackling constraints in previous research, like limited sample sizes and insufficient methodological rigor. These contributions open the path for better-informed policymaking and help to create a sustainable equilibrium between environmental protection and economic growth.

2. Literature Survey

2.1 External Debt Nexus Renewable energy consumption

The relationship between external debt and renewable energy consumption is not deterministic. It relies on diverse factors, including government policies, investment decisions, available financial resources, and global economic circumstances. Although an addition in external debt does not directly cause an increase in renewable energy consumption (and vice versa), there can be interconnected impacts and dependencies between these aspects within a country's economic and energy landscape, mainly because green external debt can significantly enhance clean energy consumption. For instance, Zheng *et al.* (2023), Xu *et al.* (2022), and Hu *et al.* (2022) suggest that green external financing can settle financial limitations and encourage renewable energy deployment, assembling the role of public debt facilitative to promoting renewable energy projects. Conversely, Campiglio (2016) ascertained that loans represent a considerable standard source of external finance for the private sector for projects related to renewable energy. Institutional solid quality and the utilization of renewable energy sources could aid in mitigating the trade-offs between environmental quality and economic growth, as well as reducing the adverse environmental effects of external debt (Akam *et al.,* 2021). External debt can benefit countries looking to invest in renewable energy projects. By borrowing money, governments can access advanced technologies and expertise from lenders or partners, which can help increase their renewable energy consumption (Sadiq *et al.,* 2022). Renewable energy projects often need infrastructure development, which can be funded through external debt. This funding helps construct solar farms, wind turbines, and hydroelectric plants, increasing renewable energy consumption (Steffen, 2018). Additionally, borrowing allows countries to invest in renewable energy education, research, and skill development, leading to a more knowledgeable workforce capable of innovating and implementing renewable energy solutions.

Conversely, increased external debt might limit a country's capacity to invest in renewable energy. A substantial portion of government expenditure may go towards servicing debt, leaving fewer resources for renewable energy development and adoption (Saleem Jabari *et al.,* 2022). Moreover, Sen and Ganguly (2017), Jianhua (2022), and Ng and Tao (2016) agreed that high costs associated with external financing can also negatively affect the renewable energy sector, and utilizing external debt for investment in specific sectors can lead to a surge in energy demand, which can have damaging environmental consequences. Repaying external debt can be costly due to interest payments, limiting a country's budget for investing in renewable energy and hindering consumption growth (Siddique *et al.,* 2016), (De Jager *et al.,* 2008). High external debt levels can lead to economic instability and may cause governments to prioritize immediate economic needs over long-term renewable energy investments, negatively impacting consumption. In some cases, countries with high external debt may prioritize exploiting their fossil fuel resources to generate revenue for debt repayment instead of investing in renewable energy, which can hinder the transition to cleaner sources of energy (Pueyo, 2018). High debt levels in a country can negatively impact investor perception and confidence in its economic stability, which could discourage foreign direct investment in renewable energy projects, leading to a decrease in renewable energy consumption.

Even though external debt is, in some cases, positively correlated and, in some scenarios, adversely related to renewable energy consumption, several studies, including Jianhua (2022), have also concluded that the relationship between external debt and renewable energy consumption is insignificant. Moreover, Sadiq *et al.* (2022) found that external debt's impact on renewable energy consumption has minimal long-term significance as debt allocation toward alternative energy resources indicates negligible influence on overall renewable energy consumption (Ramzan *et al.,* 2023). In contrast to BIMSTEC, Turkey's abundant renewable energy resources show no significant long-term correlation with external debt in its goal of environmental sustainability (Katircioglu & Celebi, 2018). From such observations, external debt can also possess a negligible effect on renewable energy consumption.

2.2 Remittances and Renewable Energy Consumption

The connection between more remittances and greater use of renewable energy may be obscure since they relate to different aspects of a country's economy. However, there are indirect ways in which higher remittances could lead to an increase in the adoption of renewable energy sources. Analyzing the trend of renewable energy consumption as remittance increases has been the primary focus of research examining the effects of financial globalization on environmental quality. Karmaker *et al.* (2023) show a positive connection between remittances and the use of renewable energy in the top 25 countries that receive remittances. Governments have the opportunity to encourage households receiving remittances to adopt affordable carbon-neutral energy devices, encouraging a more comprehensive societal uptake of green energy. Rahman and Amin (2018) also advocated that long-term data in Bangladesh shows a favorable connection between total commercial energy and renewable energy consumption, proposing that remittances contribute. Within the BIMSTEC, energy usage strongly impacts remittances, indicating that adopting renewable energy is beneficial. Taxation and subsidies promote the transition from fossil fuels to renewable sources (Rahman *et al.,* 2023).

The impact of remittances on community development projects is a topic of interest. Studies by Bada (2016) and Capellán-Pérez *et al.* (2018) found that when communities or local governments allocate a portion of these funds towards infrastructure development, there is potential for investment in renewable energy initiatives, which may include establishing renewable energy projects, like community solar installations or wind farms. Simionescu and Dumitrescu (2017) conducted a study in 74 developing countries over a period spanning from 1989 to 2015 and suggested that higher remittance inflows can positively affect a country's economy. Governments may utilize the increased revenue or improved creditworthiness resulting from these inflows to invest in sustainable development initiatives. Remittances play a significant role in supplementing household incomes, thereby increasing disposable income. According to Gupta *et al.* (2019), this additional financial capacity can potentially drive investments in renewable energy technologies, including solar panels and energy-efficient appliances.

Higher remittances may inadvertently sustain a reliance on conventional energy sources as families prioritize more affordable and familiar alternatives over long-term sustainability (Brown et al., 2020). Unintentionally, the government's impetus to allocate resources towards renewable energy infrastructure or policies could be diminished due to this trend, as it could alleviate imminent financial constraints. So, the government should set the tone for the clean energy transition (Cao *et al.,* 2021). Furthermore, regions that experience substantial remittance effects may experience market distortions caused by preferential policies or subsidies that favor conventional energy sources, thereby impeding the competitiveness of renewable energy (Kortum & Weisbach, 2021). Furthermore, despite enhanced financial resources, societal attitudes toward sustainability may be delayed, as increased remittances could overshadow endeavors to incentivize or raise awareness regarding adopting renewable energy, which could result in a need for more educational initiatives and marketing campaigns that advocate for sustainable alternatives.

2.3 Urbanization and Renewable Energy Consumption

This study by Sheng *et al.* (2017) analyzed data from 78 countries between 1995 and 2012. Using a generalized method of moments estimation, the researchers found that urbanization significantly affects energy consumption. Additionally, they observed that the impact of urbanization on energy inefficiency is more substantial in countries with higher gross product per capita. Consequently, Avtar *et al.* (2019) found that rapid urbanization puts significant pressure on infrastructure development, resulting in a heavy dependence on traditional energy sources to fulfill the immediate energy requirements. In densely populated urban areas, the implementation of renewable energy infrastructure such as solar panels or wind farms is hindered by spatial constraints caused by limited space (Palmas et al., 2015). In addition, it is worth noting that although renewable energy holds great potential for long-term sustainability, the initial expenses associated with its implementation may discourage urban populations, particularly in light of financial limitations and the high cost of living (Qamruzzaman *et al.,* 2024; Qamruzzaman & Kor, 2024; Xiangling & Qamruzzaman, 2024; Yi & Qamruzzaman, 2024). As a result, they may opt for more immediately affordable conventional energy sources. The growing need for energy in urban areas often leads to a focus on easily accessible conventional energy sources rather than investing in renewable energy systems. Urban areas are advantageous for promoting renewable energy adoption because they have a mix of socioeconomic groups, making it easier to implement inclusive programs that focus on affordability and accessibility (Cantarero, 2020). Urban areas are increasingly adopting development strategies that align with global sustainability goals, such as the UN's Sustainable Development Goals (SDGs). However, a study by Kammen and Sunter (2016) explored that urban areas, driven by the goal of optimizing resources, frequently use renewable energy sources to meet their energy requirements effectively. This results in allocating funds towards implementing rooftop solar panels or community solar projects. Mishra and Singh (2023) agreed that the pursuit of efficiency aligns with the swift adoption of new technologies in urban centers, which fosters a strong inclination towards innovation and drives the acceptance of renewable energy solutions. Abdmouleh *et al.* (2015) and Sen and Ganguly (2017) suggested that policy frameworks have been established to prioritize sustainability in certain urban regions. These frameworks encourage or even require using renewable energy in development plans and building codes, which drives the adoption of cleaner energy sources. In addition, Kammen and Sunter (2016) documented that the increased population densities in urban areas create opportunities for economies of scale in renewable energy initiatives, making it more viable to implement large-scale projects such as urban solar farms or wind turbines. The growing support for renewable energy adoption is fueled by grassroots movements in urban communities dedicated to environmental causes. These movements are playing a crucial role in raising awareness and promoting initiatives for the integration of renewable energy. Concurrently, the continuous growth of urbanization provides a favorable prospect for incorporating renewable energy infrastructure into development plans, including smart grids and environmentally friendly buildings (Hoang & Nguyen, 2021).

2.4 Political Stability and Renewable Energy Consumption

A study by Denmark and the United States found that political stability fosters an environment favorable for investment in renewable energy projects from both domestic and foreign sources. This is because it provides investors with confidence in the safety of their funds and promotes the allocation of resources towards renewable energy infrastructure and technologies (Mendonça *et al.,* 2018). Subsequently, this stability enables the establishment of enduring and consistent policy frameworks, which empowers governments to enact sustainable energy policies and offer incentives for renewable energy initiatives—all while circumventing the frequent disruptions and policy reversals frequently linked to political instability (Yan *et al.,* 2023). A study in Canada from 1990 to 2018 controlling economic growth and trade globalization by using an innovative, dynamic ARDL method found that political stability elevates a country's appeal as a destination for international collaborations and funding partnerships, which facilitates the acquisition of vital resources such as financial support, technology transfers, and specialized knowledge essential for the progression of renewable energy endeavors (Adebayo, 2022). The enhanced regulatory framework, characteristic of countries with stable governments, consists of explicit, transparent, and investor-friendly regulations. These regulations optimize renewable energy project procedures, cultivating a more favorable milieu for business (Altenburg, 2011). Politically stable nations are better equipped to prioritize long-term energy security and diversification strategies. As a result, renewable energy sources become an indispensable element of a diversified energy portfolio, diminishing dependence on unstable energy sources (Kucharski & Unesaki, 2015). In addition, political stability promotes public trust and confidence in governmental endeavors, which increases public participation and support for renewable energy programs, as well as public consciousness and acceptance of renewable energy solutions, entice investments in infrastructure development, such as the modernization of utility systems and the adaptation of infrastructure to facilitate the integration of renewable energy sources, thereby increasing their efficiency and accessibility (Michael Mullan, 2018), (LINK, 2023). Political stability is crucial for consistent and long-term planning in the renewable energy sector. Governments in stable environments can set ambitious renewable energy targets and effectively implement policies to achieve them. This stability promotes policy consistency and encourages sustained investment and innovation in the sector (Burke & Stephens, 2018). Investors feel more secure in committing funds to renewable energy projects in politically stable countries, which attracts long-term investments (Pueyo, 2018). Additionally, politically stable countries are more likely to engage effectively in international collaborations and agreements related to renewable energy, benefiting from shared expertise and resources. Finally, stable political environments enable the development of robust institutions capable of effectively regulating and promoting the growth and stability of the renewable energy sector. In stable political environments, there is a risk aversion towards policy experimentation, which hinders the adoption of innovative renewable energy policies and technologies. Stability ensures consistent policies but can lead to inertia and difficulty adapting to technological advancements and global energy trends. Resistance to change from established industries benefiting from traditional energy sources slows the transition to renewable energy. A lack of urgency in addressing energy challenges can overshadow the need for urgent action on renewable energy transitions. Complex decision-making processes and bureaucratic hurdles in stable political environments can slow the implementation of renewable energy policies or projects. Stable political climates discourage experimentation with alternative energy sources, favoring proven methods over potentially more sustainable options(Md Qamruzzaman, 2024a; Yin & Qamruzzaman, 2024).

2.5. Limitations in the existing literature

The current research on the relationship between external debt, remittances, political stability, urbanization, and renewable energy consumption in BIMSTEC nations has several limitations. These include studies that use small or unrepresentative samples, making applying the findings to a larger population easier. Establishing cause-and-effect relationships between these variables is challenging due to endogeneity issues and the need for robust methodologies like randomized control trials. The data quality used in different studies may vary, leading to potential inaccuracies or biases in the results. Many studies overlook essential variables that could significantly influence the relationships between these factors, such as technological advancements, governance indicators, environmental policies, or income inequality. This omission can result in biased or incomplete interpretations of the connections among these elements. To address these limitations, a more inclusive approach is needed, incorporating a broader range of relevant variables to understand better the dynamics between external debt, remittances, political stability, urbanization, and renewable energy consumption in BIMSTEC nations. Using comprehensive models encompassing a wider range of variables would likely improve the accuracy and depth of insights for regional policymaking.

3. Methodology of the study

3.1 Theoretical development and Model Specification

Theoretical frameworks play a crucial role in interpreting and analyzing the intricate interconnections among variables like external debt, remittances, political stability, urbanization, and renewable energy consumption. By integrating theories from economics, political science, and sustainability studies, these frameworks offer a systematic method for comprehending the interactions among these factors that shape energy policy and investment choices.

External debt represents a crucial macroeconomic factor that can greatly influence government policy, especially energy investments. The debt-overhang hypothesis suggests that substantial external debt may redirect resources away from productive investments towards debt servicing, hindering potential investments in renewable energy infrastructure (Baker *et al.,* 2014). Governments might focus on short-term economic stabilization rather than long-term sustainability in nations burdened by significant debt, potentially obstructing renewable energy projects (Gaies & Nabi, 2021). On the other hand, external debt may act as a driving force for adopting renewable energy, particularly when associated with conditional loans from international financial institutions that support green energy initiatives (Poudineh *et al.,* 2018). The dual role of external debt highlights the necessity for meticulous financial governance to reconcile short-term fiscal pressures with long-term energy objectives.

Remittances are a vital financial inflow for numerous developing economies and exhibit a multifaceted relationship with renewable energy consumption. On the one hand, remittances can improve household disposable income, allowing for investments in renewable energy technologies like solar panels (Subramaniam et al., 2022). Conversely, the distribution of remittances frequently reflects the priorities of individuals or communities, which might not consistently correspond with renewable energy goals (Akçay & Demirtaş, 2015). The possibility for remittances to indirectly bolster renewable energy initiatives emerges when governments leverage these inflows to alleviate fiscal deficits, thus releasing resources for energy projects (Das *et al.,* 2021a), which underscores the significance of focused policy measures that can direct remittance flows towards the advancement of sustainable energy initiatives.

Political stability is vital in ensuring effective governance and facilitating long-term energy planning. A stable political environment promotes the development and execution of renewable energy policies, drawing in foreign direct investments and stimulating innovation (Bonvin, 2011). Conversely, political instability can potentially disrupt energy markets and redirect governmental attention to pressing security or economic recovery matters, which can consequently deter investment in renewable energy (Zhao & Qamruzzaman, 2022). Understanding risk linked to political instability frequently results in a tendency to favor short-term energy solutions, potentially hindering the shift towards more sustainable energy systems. Therefore, political stability plays a crucial role in fostering an environment that encourages investments in renewable energy.

The impact of urbanization on energy demand patterns is substantial, as growing urban areas generally necessitate increased energy to sustain their development. This demand brings various challenges and opportunities for integrating renewable energy into urban infrastructure (Marandino, 2025). Urbanization can drive technological progress and increase energy consumption; however, unplanned urban expansion may put pressure on current resources and infrastructure, making it more challenging to implement renewable energy solutions (Abdullah, 2021). The connection between urbanization and energy consumption highlights the necessity for efficient governance and creative urban planning approaches emphasizing sustainable energy practices (Sager-Klauss, 2015).

The relationship between external debt, remittances, political stability, and urbanization illustrates interconnections that influence energy policy and investment choices. The interplay of these variables significantly affects a government's ability and readiness to focus on renewable energy investments and influences the demand and funding strategies for these solutions. A multi-dimensional approach to energy policy is crucial, as it integrates economic, social, and political factors to effectively tackle barriers and capitalize on opportunities for renewable energy adoption. Achieving sustainable energy transitions requires well-structured policies that consider the interconnected dynamics of these variables systematically and context-specific (Bantimaroudi *et al.,* 2023).

Earlier studies indicate that remittances, urbanization, political stability, and external debt collectively influence energy consumption in BIMSTEC countries from 1995 to 2021. Prior studies suggest that both macroeconomic and microeconomic factors influence energy consumption patterns. Researchers have developed a comprehensive empirical model to clarify the correlation among these variables.

$$REC \mid (ED, REM, UR, PS) \qquad (1)$$

The measurement of energy consumption is conducted by utilizing three distinct metrics: EC, NREC, and REC. This study investigates the influence of External Debt (ED), Remittance (REM), and Urbanization (UR) on the consumption of energy. The equation (1) has been revised to include these variables:

$$REC_{it} = \alpha_0 + \beta_1 lnED_{it} + \beta_2 lnREM_{it} + \beta_3 lnUR_{it} + \beta_4 lnPS_{it} + \varepsilon_t + \varepsilon_{it} \qquad (2)$$

3.2 Variables definition and sources and expected effects on deponent variable

External debt refers to the complete liabilities owed overseas creditors, which may consist of governments, international entities, and private lenders. It is generally expressed as a percentage of a country's Gross Domestic Product (GDP). Information regarding external debt can be obtained from credible organizations like the World Bank and the International Monetary Fund (IMF). Elevated external debt levels frequently align with adverse economic consequences, such as diminished economic growth and heightened susceptibility to financial crises, since excessive debt can constrain a government's capacity to invest in vital public services and infrastructure (Avtar *et al.,* 2019; Azam *et al.,* 2016). The choice to focus on external debt as a variable stems from its significant influence on fiscal policy and the long-term economic viability of a country, as it can affect investor confidence and the broader economic landscape (Onafowora, 2024).

Remittances are the funds migrants send back to their home countries, significantly contributing to household income and strengthening national foreign exchange reserves. Remittance information is generally accessible through the World Bank and national central banks (De Jager *et al.,* 2008). The anticipated beneficial impact of remittances on economic development is thoroughly documented; they can enhance consumption, elevate household welfare, and offer funding for education and health services. This variable holds significant importance in developing countries, where remittances frequently stabilize income and consumption patterns, thus enhancing economic resilience (Hoang & Nguyen, 2021).

Political stability refers to the lack of violence, terrorism, and political unrest and is frequently measured using indices like the World Governance Indicators (WGI). A stable political environment is anticipated to enhance economic performance by establishing a favorable setting for investment and innovation (Kucharski & Unesaki, 2015). The inclusion of political stability as a variable is highlighted by its vital importance in shaping investor confidence and the effectiveness of institutions, both of which are crucial for sustained economic growth. Empirical evidence indicates that political stability positively impacts economic growth, as it reduces investment-related risks and fosters a predictable economic environment.

Urbanization denotes the rising proportion of individuals residing in urban locales, with information generally obtained from the United Nations and the World Bank (Blum & Gründler, 2020). The impact of urbanization on economic development is complex; it can enhance productivity and foster innovation via agglomeration economies, yet it may also intensify challenges like inequality and environmental degradation. The inclusion of urbanization as a variable is justified by its considerable impact on infrastructure development, labor market dynamics, and resource allocation, all of which are essential for sustainable economic growth (Qamruzzaman *et al.,* 2024)

Renewable energy consumption quantifies the proportion of overall energy usage that comes from renewable sources, including solar, wind, and hydroelectric power. Data from the International Renewable Energy Agency (IRENA) and the World Bank can be sourced. The increased reliance on renewable energy is expected to positively influence economic sustainability, enhance environmental quality, and bolster energy security (Siddique et al., 2016). This variable is chosen because of its increasing significance in tackling climate change and promoting sustainable economic development as nations move towards more environmentally friendly energy options.

3.3 Estimation strategy

To begin, the concern regarding intersectional dependence is examined by employing the methodology suggested by (Juodis and Reese, 2022). The present methodology for evaluating "Cross-sectional Dependence" (CD) distinguishes itself from traditional CD-testing approaches by assuming weak dependencies (Figure 1).

The dependence between cross-sections is confirmed for the respective variable by the statistical significance of the test statistic predicted by this test. Furthermore, the approach suggested by Bersvendsen and Ditzen (2021) is implemented to determine whether heterogeneous slope coefficient-related issues are present. The "Slope Heterogeneity" (SH) testing method, which was recently introduced, predicts test statistics assuming that slope coefficients are distributed uniformly across various cross-sectional units, thereby controlling for CD-related concerns in the data. Therefore, the statistical significance of these test statistics will validate the presence of SH in the model under consideration.

Thirdly, to ascertain the integration of the variables under consideration (i.e., whether they are stationary and their respective series are mean-reverting), the method suggested by (Herwartz and Siedenburg, 2008) is employed to conduct the unit root analysis. (Murshed, 2023) describes this technique as a CD-adjusted panel unit root estimation method that eliminates slight sample bias via random bootstrapping and modification mechanisms. It is worth mentioning that the procedure proposed by (Herwartz and Siedenburg, 2008) predicts a single test statistic for each variable, either at the level or the first

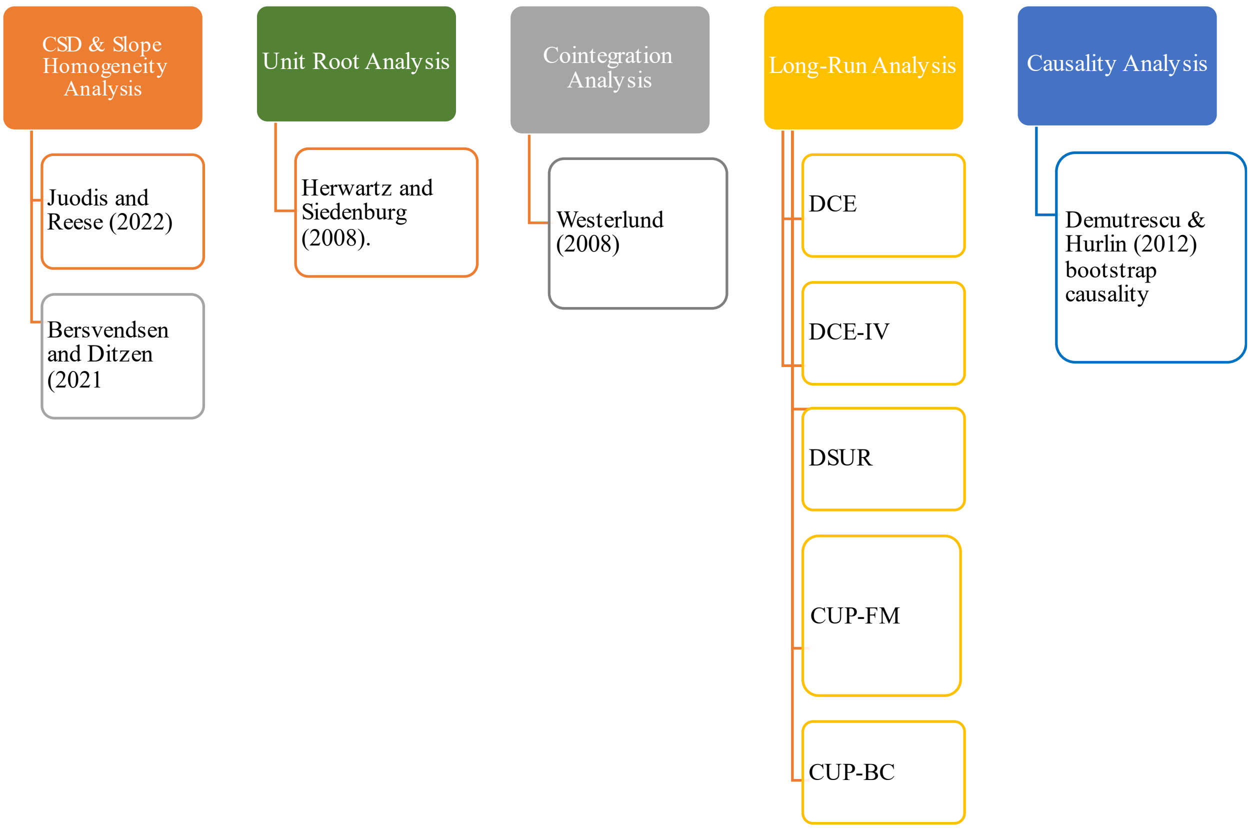

Fig 1. Flow of estimation strategies

difference, assuming that the series in question remains non-integrated and non-stationary.

In the existing body of literature, empirical estimates with panel data have argued for evaluating the research unit's intrinsic qualities before the target model's implementation. By the existing body of research, the current investigation has carried out a test of heterogeneity, followed by a CSD test, using the equation presented below:

$$CD = \sqrt{\frac{2T}{N(N-1)}}\sum_{i=2}^{N}\sum_{j=1}^{i-1}\hat{\rho}_{ij} = \sqrt{\frac{TN(N-1)}{2}}\,\bar{\hat{\rho}} \qquad (3)$$

Here,

$$\hat{\rho}_{ij} = \frac{T^{-1}\sum_{t=1}^{T}(z_{i,t}-\bar{z}_i)(z_{jt}-\bar{z}_j)}{\sqrt{T^{-1}\sum_{t=1}^{T}\left(z_{i,t}-\bar{z}_i\right)^2}\sqrt{T^{-1}\sum_{t=1}^{T}\left(z_{jt}-\bar{z}_j\right)^2}} \qquad (4)$$

To select the appropriate econometric instruments, it is essential to investigate the stationary features of the study variables. According to previous research findings, the first generation's unit root test is inappropriate for static testing situations with cross-sectional reliance. In this investigation, we utilize the second-generation unit root test. More specifically, we use the CADF and CIPS tests established by (Pesaran, 2007). Applying the following equations will allow you to obtain the test statistics for the static test.

$$\Delta Y_{it} = \mu_i + \theta_i y_{i,\ t-1} + \gamma_i \bar{y}_{t-1} + \theta_i y_{i,\ t-1} + \vartheta_i \bar{y}_t + \tau_{it} \qquad (5)$$

$$\Delta Y_{it} = \mu_i + \theta_i y_{i,\ t-1} + \gamma_i \bar{y}_{t-1} + \sum_{k=1}^{p}\gamma_{ik} \triangle y_{i,\ k-1} + \sum_{k=0}^{p}\gamma_{ik}\,\overline{\triangle y}_{i,\ k-0} + \tau_{it} \qquad (6)$$

$$CIPS = N^{-1}\sum_{i-1}^{N}\partial_i\,(N,T) \qquad (7)$$

$$CIPS = N^{-1}\sum_{i-1}^{N} CADF \qquad (8)$$

The research utilized a panel cointegration test to investigate the association between variables over an extended period. Westerlund's error correction-based cointegration test was another method they used in their experiments. With the help of two different sets of test statistics, the research endeavoured to test the null hypothesis that there was no cointegration.

$$\Delta Z_{it} = \partial_i d_i + \emptyset_i\left(Z_{i,t-1} - \delta_\iota \acute{W}_{\iota,t-1}\right) + \sum_{r=1}^{p}\emptyset_{i,r}\,\Delta Z_{i,t-r} + \sum_{r=0}^{p}\gamma_{i,j}\,\Delta W_{i,t-r} + \varepsilon_{i,t} \qquad (9)$$

$$G_T = \frac{1}{N}\sum_{i-1}^{N}\frac{\varphi_i}{SE\varphi_i} \qquad (10)$$

$$G_T = \frac{1}{N}\sum_{i-1}^{N}\frac{T\varphi_i}{\varphi_i(1)} \qquad (11)$$

$$P_T = \frac{\varphi_i}{SE\varphi_i} \qquad (12)$$

$$P_a = T\varphi_i \tag{13}$$

Finally, a panel regression analysis is conducted to examine the relationship between long-term carbon intensity figures of the BIMSTEC nations and positive changes in external Debt, remittances, political stability, and urbanization; the proportion of renewable energy in the "total final energy consumption portfolio''. This study uses two-panel regression methods adjusted for CD and SH. Initially, the dynamic panel regression technique known as "Dynamic Common Correlated Effects" (DCE), which was introduced by Chudik and Pesaran (2015), is utilized. In order to address the limitations of Pesaran's (2006) static common correlated effects estimator, which is unsuitable for estimating models containing lagged outcome (i.e., lagged-dependent) variables as covariates and cannot manage weakly exogenous variables (Chudik & Pesaran, 2015), this approach was developed. However, while the Pesaran (2006) method applies to data sets containing SH and CD-related concerns, it only applies if adequate delays and cross-sectional averages are incorporated into the model (as with the DCE estimator). The DCE estimator provides three estimation procedures; nevertheless, the "Cross-sectional Augmented Distributed Lag" model is selected for this research.

While the DCE estimator Chudik and Pesaran's (2015) proposal offers numerous benefits, it is most effectively applied to extensive panel data sets. However, this estimator allows for incorporating recursive mean adjustment and jackknife bias correction techniques to account for finite sample bias in small panel data sets. Moreover, introducing the lagged outcome variable as a covariate could potentially lead to endogeneity concerns arising from issues related to reverse causation. When faced with such conditions, the results obtained through the DCE method are prone to contain bias. Therefore, an extra regression technique is implemented, employing an instrumental variable approach in the DCE estimation configuration to account for endogenous covariates that may exist in the model.

This study also employs the instrumental variable-adjusted DCE method (henceforth DCE-IV), suggested by Ditzen (2018). It is worth mentioning that the DCE-IV estimator incorporates latent levels of covariates as regressors, which serve as mechanisms to offset the effects of endogenous covariates.

A prevalent statistical framework, Dynamic Seemingly Unrelated (DSUR) models enable the examination of potentially interrelated time series data sets across multiple instances. The statistical method called Cointegrating Regression (DSUR) estimates equations demonstrating cointegration. Cointegration, which signifies the presence of a unit root among non-stationary variables, refers to the persistent relationship between them. The estimation of this relationship is facilitated by the DSUR methodology, which considers the dynamic character of the variables involved. In the context of DSUR, it is critical to specify that the Ordinary Least Squares (OLS) method is utilized to estimate each equation within the system individually.

The DSUCR model can be represented as follows:

$$\begin{aligned}\Delta Y_{it} = \alpha_i + \beta_i Z_{it} + \sum j &= 1p\phi ij\Delta Y_{it}, t-j \\ &+ \sum k = 1q\theta ik\Delta Zi, t-k + \varepsilon it\Delta Y_{it} \\ &= \alpha_i + \beta_i Z_{it} + \sum j = 1p\phi ij\Delta Y_{i,t} - j + \sum k \\ &= 1q\theta ik\Delta Z_{i,t} - k + \varepsilon_{it}\end{aligned} \tag{14}$$

Bai (2009) has established that the CUP-FM and CUP-BC methods yield a reliable estimation. Furthermore, until convergence is achieved, CUP-FM and CUP-BC can generate covariance matrix estimations, continuous parameters, and factor loadings.

$$\beta_{cup}=\left[\sum_{i=1}^{N}\left(\sum_{t=1}^{T}\hat{y}_{it}+\hat{\beta}_{cup}\right)(x_{it}-\bar{X}_i)'\right] - \left[T\left(\lambda'_i(\hat{\beta}_{CUP})\hat{\Delta}_{F\varepsilon i}(\hat{\beta}_{CUP})\right)+\hat{\Delta}_{u\varepsilon i}(\hat{\beta}_{CUP})\right] \times \left[\sum_{i=1}^{N}(x_{it}-\bar{X}_i)(x_{it}-\bar{X}_i)'\right] \tag{15}$$

This work addresses the issue of cross-sectional dependence. It provides an accurate estimate using a smaller number of observations (N) and a more significant number of trials (T) by utilizing the Granger causality test, which Dumitrescu and Hurlin proposed(Dumitrescu & Hurlin, 2012). The individual Wald statistics' progressive convergence is a prerequisite for passing the test. The standard Wald statistics for the panel causality test are as follows:

$$Y_{it} = \alpha_i + \sum_{K-1}^{P}\gamma_{ik}Y_{i,t-k} + \sum_{K-1}^{P}\beta_{ik}X_{i,t-k} + \mu_{it} \tag{16}$$

$$W_{NT}^{Hnc} = N^{-1}\sum_{i-1}^{N}W_{i,t} \tag{17}$$

$$Z = \sqrt{\frac{N}{2P}\times\frac{T-2P-5}{T-P-3}} \times \left[\frac{T-2P-3}{T-2P-1}\bar{W}-P\right] \tag{18}$$

The Dumitrescu and Hurlin (2012) Panel Causality Test is a suitable option for empirical assessment. It may examine causal linkages between external debt, remittances, urbanization, political stability, and renewable energy sources within a panel data framework. This test provides strong inference in the presence of national heterogeneity while considering cross-sectional dependence. Using this test, we can determine the degree and direction of causality across variables, providing insight into the dynamic interactions between urbanization, renewable energy use, remittances, and external debt. Formulating policies and deciding to encourage renewable energy sources and sustainable development in BIMSTEC member states will help create antecedent relationships.

4. Estimation and interpretation

The VIF analysis, see Table 1, assesses multicollinearity among the variables, a phenomenon where predictors in a regression model exhibit high correlation, potentially impacting result reliability and interpretation. VIF scores above 5 or 10 are typically problematic, indicating severe multicollinearity. In this study, the variable LnDEBT has a VIF of 4.7735, suggesting moderate correlation but not exceeding critical thresholds. Other variables (RECS, PS, REM, LnURBAN, LnTP, and TOPEN) exhibit lower VIF values (1.6054 to 3.4947), indicating less severe multicollinearity. The "1/VIF" column underscores relative independence, revealing that LnDEBT maintains a higher degree of independence. The mean VIF of 2.8052 falls within an acceptable range, suggesting that multicollinearity is not a significant concern, and the regression results remain reliable.

The findings from the CD and SH tests (see Table 2), conducted following the methodologies suggested by Juodis and Reese (2022) and Bersvendsen and Ditzen (2021), are

Table 1
Outputs from VIF analysis

Scores	LnDEBT	RECS	PS	REM	LnURBAN	LnTP	TOPEN
VIF	4.7735	1.6054	2.0039	3.4947	2.4103	2.5462	2.8024
1/VIF	0.2094	0.6228	0.499	0.2861	0.4148	0.3927	0.3568
Mean VIF	2.8052						

Table 2
Results of the CD test and SH test

Panel A: CD test of Juodis and Reese (2022)							
	LnDEBT	**RECS**	**PS**	**REM**	**LnURBAN**	**LnTP**	**TOPEN**
test stat value	-3.7919	5.6877	-1.7876	4.4085	-0.5988	2.83	6.29
Probability		***		***	***	***	***
CD exist	#N/A	YES	#N/A	YES	YES	YES	YES
Panel B: SH test of Bersvendsen and Ditzen (2021)							
	Delta	Statistic	Adjusted	Delta	Statistic	SH	exits
Model	4.6839***		4.9814***			Yes	
Model	3.6284***		4.0662***			Yes	

outlined in Table 4 and comprehensively analyzed. The results indicate statistically significant predicted test statistics for variables such as LnDEBT, LnFDI, RECS, LnURBAN, LnTP, and TOPEN, while variables like LnDEBT, PS, and REM display statistical insignificance. Conversely, in the scope of slop heterogeneity (SH), Models 1 and 2 exhibit statistical significance in the Delta and adjusted Delta statistics, rejecting the null hypothesis and confirming the presence of SH-related issues within the data. This finding aligns with the notable differences among BIMSTEC nations in various macroeconomic aspects, justifying the observed heterogeneity in the slope coefficients.

The results obtained from integration and cointegration analyses, as suggested by Herwartz and Siedenburg (2008) and Westerlund (2008), are presented in Table 3, respectively. It is observed that the estimated test statistics for Models 1 and 2 exhibit statistical significance. Therefore, to corroborate the existence of cointegration associations among the variables under consideration, the null hypothesis can be rejected.

A positive coefficient for external debt (see

Table **4**) suggests that an increase in external debt is associated with an increase in renewable energy consumption. Furthermore, as demonstrated, the coefficient of "rec (-1)" is negative, indicating that when the value of "rec" in the previous period increases, the current value of "rec" decreases. In both the DCE model and the DCE-IV model, the positive coefficients for external debt (0.14961 and 0.10094, respectively) indicate that increased debt is associated with increased renewable energy consumption. In contrast, the DCE-IV model portrays a slightly lower coefficient for debt at 0.10094. Here, a 10% increase in the debt corresponds to an approximate 1.0094 increase in renewable energy consumption. For the DCE model, a 10% increase in the variable corresponds to an approximate 1.4961 increase in renewable energy demand. Although both models indicate a positive relationship between these variables, they show a slightly smaller proportional increase in renewable energy than in the DCE model, suggesting that the relationship between debt and REC may not be as strong as it seems.

For the DCE and the DCE-IV models, the coefficients for remittance are 0.1026 and 0.16567, respectively, which signifies a positive relationship between the remittances and the REC. Hence, an increase in remittances is associated with an increase in REC, holding other factors unchanged. In the DCE model, a 10% increase in remittance is associated with roughly a 1.026% increase in the REC. In the DCE-IV model, an increase of 10% is associated with approximately a 1.6567% increase in the REC, which is slightly higher than the DCE model. Various factors influence the positive nexus between remittances and renewable energy consumption. Studies indicate that remittances can contribute to higher energy consumption, particularly in the renewable energy sector, giving households more purchasing power.

Higher values of urbanization may correspond to higher unemployment rates, as indicated by the positive coefficients (0.0926 in DCE and 0.17369 in DCE-IV). This relationship implies that greater urbanization leads to greater REC. According to the DCE model's estimation, a 10% increase in urbanization is associated with roughly a 0.926% increase in renewable energy demand. In the DCE-IV model, a 10% increase in urbanization is associated with approximately a 1.7369% increase in renewable energy demand., which suggests a comparatively stronger relationship between urbanization and the demand for renewable energy in the DCE-IV model compared to the DCE model's estimation. Several factors contribute to the positive correlation between urbanization and renewable energy consumption; for instance, as cities grow, they consume more energy, creating a need for renewable energy to meet the increasing demand (Sheng et al., 2017).

In the DCE model, the political stability has a coefficient of 0.1563, while in the DCE-IV, the coefficient is 0.12534. This implies a positive relationship between political stability and REC. Again, in the DCE model, a 10% increase in political stability is associated with roughly a 1.563% increase in the

Table 3
Results from integration and cointegration tests

Panel	A: Integration (or unit-root) test of Herwartz and Siedenburg -2008 Analysis						
	LnDEBT	**RECS**	**PS**	**REM**	**LnURBAN**	**LnTP**	**TOPEN**
At a level	1.561	-0.368	-0.2302	1.4679	1.6528	1.0498	1.6654
After first difference	-2.7264***	-2.6224***	1.8282*	2.2682***	3.3416***	4.6722***	-3.9813***

Panel B: Cointegration test of Westerlund and Edgerton (2008)						
	no shift		mean shift		regiem shift	
	LMr Stat.	LMΦ Stat.	LMr Stat.	LMΦ Stat.	LMr Stat.	LMΦ Stat.
Model 1	-3.2356	-4.9121	-2.0624	-2.8493	-4.923	-2.1817
Model 2	-4.7862	-4.448	-2.4494	-4.3381	-3.6857	-4.3204

Table 4
Coefficient estimation: DCE and DCE-IV

	Coefficient	Std. Error	t-Statistic	Coefficient	Std. Error	t-Statistic
	DCE			DCE-IV		
REC (-1)	-			-0.09514***	0.043	-2.2125
DEBT	`0.1496***	0.0252	5.9369	0.10094***	0.0359	2.8116
REM	0.1026***	0.0301	3.4086	0.16567***	0.0245	6.762
UR	0.0926***	0.0418	2.2167	0.17369***	0.039	4.4535
PS	0.1563***	0.0284	5.5035	0.12534***	0.0466	2.6896
TO	0.1385***	0.0207	6.6908	0.14613***	0.0343	4.2603
FDI	0.10891***	0.033	3.3003	-0.70382***	0.0387	-18.1865
C	-16.239***	0.24013	-67.6258	-11.732***	0.24013	-48.8568
Adj R2	0.8945			0.9068		
R^2	0.9439			0.9234		

REC. However, in the DCE-IV model, an increase of 10% in political stability increases the REC by 1.2534%. Thus, regarding the estimated impact on the REC, the DCE model indicates a relatively more significant effect than the DCE-IV model. Research also indicates that implementing supportive policies and government actions can encourage the use of renewable energy. One study discovered that government incentives and policies, like feed-in tariffs and renewable portfolio standards, can effectively promote the adoption of renewable energy sources (Kolkowska, 2023).

The positive coefficients (0.1385 in the DCE model and 0.14613 in the DCE-IV model) imply that an addition in trade openness is associated with a boost in renewable energy demand. The DCE model has a slightly higher adjusted R-squared value (0.9439) compared to the DCE-IV model (0.9234), indicating that the DCE model may be slightly more effective in explaining variations in the REC. According to the DCE model, a 10% increase in trade openness would result in a 1.385% increase in the REC when all other factors remain constant. In the DCE-IV model, a 10% increase in trade openness would lead to a 1.4613% increase in the REC.

The FDI coefficients in the DCE and DCE-IV models are 0.10891 and -0.70382, respectively. The positive coefficient in the DCE model indicates that when FDI increases, the REC also increases. In contrast, the DCE-IV model's negative coefficient suggests that the REC decreases as FDI increases. For the DCE model, a 10% increase in FDI leads to a 1.0891% increase in REC. Conversely, for the DCE-IV model, a 10% increase in FDI leads to a 7.0382% decrease in the REC. Differences between the DCE (Discrete Choice Experiment) and DCE-IV (Instrumental Variable) models can stem from varied methods of addressing issues like endogeneity and omitted variable bias. The positive correlation between FDI and REC is justifiable and confirmed by many studies, as FDI can enhance the growth and acceptance of renewable energy technologies by introducing advanced equipment, expertise, and knowledge from other nations.

The findings derived from the robustness analysis are displayed in Table 5. Consistent with expectations, it is apparent that the robustness of the findings cannot be established because the annual REC figures per capita of the BIMSTEC nations are now impacted by all relevant factors, which was not the case previously. However, the statistical findings support that external debt, remittances, political stability, and urbanization contribute to long-term per capita CO2 emissions increase. Conversely, they confirm that greater adoption of renewable energy sources in energy systems, enhancements in institutional quality, and technological advancements result in

Table 5
Results of robustness test: DSUR, CUP-FM, and CUP-BC

	Coefficient	Std. Error	t-Statistic	Coefficient	Std. Error	t-Statistic	Coefficient	Std. Error	t-Statistic
	DSUR			CUP-FM			CUP-BC		
DEBT	0.1106***	0.0243	4.553	0.1534***	0.0377	4.0708	0.0841***	0.0436	1.9291
REM	0.1555***	0.0278	5.5949	0.0873	0.0259	3.3714	0.0975***	0.0383	2.5480
UR	0.1324***	0.0447	2.9635	0.1287***	0.0175	7.356	0.1098***	0.0441	2.4897
PS	0.0881***	0.043	2.0504	0.1319***	0.0241	5.4751	0.0789***	0.0148	5.3371
TO	-0.1451***	0.0144	-10.0763	-0.0931***	0.0235	-3.9578	-0.1475***	0.0386	-3.8222
FDI	0.1806***	0.0344	5.2511	0.2574***	0.0465	5.5359	0.2774***	0.0425	6.5277
C	12.736	0.2401	53.0379	8.265	0.24013	34.418	9.303	0.2401	38.7415
Adj R2	0.9016			0.8926			0.8967		
R^2	0.9251			0.9277			0.9484		

Table 6
DH causality test

	REC	DEBT	REM	UR	PS	TO	FDI
REC		(3.4537)** [3.6402]	(5.8193)*** [6.1335]	(3.4814)** [3.6693]	1.8597 [1.9601]	(4.7534)*** [5.0101]	(6.2263)*** [6.5625]
DEBT	(2.7343)* [2.8819]		1.6142 [1.7014]	(5.3315)*** [5.6194]	(4.5472)** [4.7928]	(4.4845)** [4.7267]	(3.9383)** [4.151]
REM	(6.1689)*** [6.502]	0.8969 [0.9453]		(4.8979)*** [5.1624]	(5.4112)*** [5.7034]	(2.5207)* [2.6568]	(3.4569)** [3.6436]
UR	(3.4378)** [3.6234]	1.4782 [1.558]	(3.5908)** [3.7847]		(3.628)** [3.8239]	(3.7003)** [3.9001]	(3.1519)** [3.3221]
PS	(5.9266)*** [6.2467]	(5.7662)*** [6.0775]	(6.2858)*** [6.6253]	(3.5111)** [3.7007]		(3.7173)** [3.918]	(3.4165)** [3.601]
TO	1.8756 [1.9769]	(5.8862)*** [6.2041]	(2.3793)* [2.5078]	1.5132 [1.595]	(5.8873)*** [6.2052]		(4.2879)** [4.5195]
FDI	(6.2784)*** [6.6174]	(4.4622)** [4.7032]	(2.7035)* [2.8494]	(3.9309)** [4.1431]	1.5727 [1.6577]	(4.3166)** [4.5497]	

decreased emissions. The table offers coefficients, standard errors, and t-statistics for various variables: DEBT (External Debt), REM, UR, PS, TO, FDI, Y, and C. For instance, DEBT exhibits a coefficient of 0.11064 with a t-statistic of 4.553, suggesting a significant impact on the dependent variable. Similarly, REM depicts a coefficient of 0.15554 with a t-statistic of 5.5949, highlighting its substantial influence. UR showcases a coefficient of 0.13247 with a t-statistic of 2.9635, indicating its moderate impact. PS is depicted by a coefficient of 0.08817 and a t-statistic of 2.0504, indicating its comparatively more minor yet significant influence. Meanwhile, TO and FDI present coefficients of 0.1451 and 0.18064, respectively, with robust t-statistics, denoting their substantial impacts. Moreover, variables Y and C exhibit exceptionally high coefficients, 0.25862 and 12.736, respectively, accompanied by notably high t-statistics, demonstrating their significant influences on the dependent variable.

The DH causality test, see Table 6, utilizes coefficients and related statistics to illuminate complex variables' interrelationships. REC displays sensitivity to external factors, evidenced by coefficients like 3.4537 and significant t-statistics (e.g., 3.6402), revealing its interplay with DEBT, REM, and others. DEBT, showcased by coefficients such as 2.7343 and t-statistics of 2.8819, showcases its potential influence on REC, REM, and UR, reflecting its relevancy. REM demonstrates substantial impact, evident in coefficients like 6.1689, with significant t-statistics, suggesting its sway over REC, DEBT, and UR, among others. UR's connections, exemplified by coefficients such as 3.4378 and t-statistics of 3.6234, highlight its associations with DEBT, REM, and PS, portraying its interdependence. PS, highlighted by coefficients like 5.9266, signifies its impact on various variables, underlining its significance. If included, FDI and TO would similarly illustrate their influences.

5. Discussion:

The coefficient for foreign debt indicates a positive correlation between the utilization of renewable energy. The DCE and the DCE-IV models exhibit positive external debt coefficients (0.14961 and 0.10094, respectively), suggesting a positive correlation between rising debt levels and increased renewable energy consumption. A 10% increase in the variable causes an estimated 1.4961% and 1.0094% rise in the demand for renewable energy, according to the DCE and DCE-IV models. Both models illustrate a positive correlation between the variables above; however, the DCE model displays a marginally higher proportionate increase in renewable energy compared to the alternative model, indicating a scenario where higher debt is associated with a rise in renewable energy consumption. However, the previous value of renewable energy consumption tends to hurt its current value. An increase in a country's external debt through the natural income channel can lead to increased projects and investments, subsequently affecting energy consumption. When a country's external debt increases, it can lead to increased projects and investments, subsequently affecting energy consumption (Saleem Jabari et al., 2022). The results of our research align with the findings of previous studies, including those conducted by Hashemizadeh *et al.* (2021), (Wang *et al.,* 2021), (Zeraibi *et al.,* 2023). Researchers have explored the impact of public debt on renewable energy consumption and found a positive linear effect on various energy-related indicators(Md Qamruzzaman, 2024b; Xiangling & Qamruzzaman, 2024). The relationship between external debt and renewable energy consumption is complex and can be influenced by factors such as governance quality, financial sector development, and environmental regulations. While some studies have demonstrated a positive association, others have shown a negative linkage between external debt and renewable energy consumption (Saleem Jabari *et al.,* 2022). A study conducted in Turkey by Saleem Jabari *et al.* (2022) found that a one percent increase in external debt caused renewable energy consumption to decrease by 0.001% in the short run and 0.017% in the long run. Similarly, Jianhua (2022) found no direct causal relationship between external debt and renewable energy consumption.

Regarding remittances, these coefficients indicate a positive correlation between remittances and the REC. Consequently, a rise in REC is associated with increased remittances, presuming all other factors remain constant. According to the DCE model, a 10% increase in remittances is associated with an approximate 1.026% increase in the REC. A 10% increase is associated with an estimated 1.6567% increase in the REC, as predicted by the DCE-IV model. This increase is considerably more significant than that predicted by the DCE model. Numerous variables influence the correlation between remittances and the utilization of renewable energy supply. By providing families with additional financial resources, remittances may increase energy consumption, particularly in the renewable energy sector (Jamil *et al.,* 2022; Karmaker *et al.,* 2023; Seury *et al.,* 2023; Subramaniam *et al.,* 2023). Literature suggests that remittances can contribute to higher energy consumption, particularly in the renewable energy sector, as they enable households to have more purchasing power (Md. Qamruzzaman, 2024; Wang *et al.,* 2024). In addition, the economic impact of remittances has been observed to influence energy demand, including the integration of clean energy sources. Various studies have discovered a generally positive correlation between remittances and the consumption of renewable energy in different countries (Karmaker *et al.,* 2023), (Das *et al.,* 2021b). However, there are some findings which contradict our findings. For instance, research has discovered a correlation between higher remittances and lower usage of renewable energy Seury *et al.* (2023). Additionally, another study has shown that remittances and energy prices reduce energy consumption, including renewable energy, in the long run.

A positive correlation has been observed between higher levels of urbanization and unemployment rates, as indicated by the coefficients of 0.17369 in DCE and 0.0926 in DCE-IV. This correlation implies that increased urbanization leads to greater levels of REC. According to the DCE model, a 10% increase in urbanization is associated with an approximate 0.926% increase in the demand for renewable energy. The DCE-IV model establishes a correlation between a 10% increase in urbanization and an approximate 1.7369% surge in the demand for renewable energy. The DCE-IV model demonstrates a stronger positive correlation between renewable energy demand and urbanization than the DCE model's estimation. The escalating demand for energy in cities necessitates the implementation of renewable energy sources, as urban expansion results in increased energy consumption. Renewable energy technologies can become more economically feasible as their costs decrease. Urban areas are often leading the way in adopting and developing new renewable energy technologies; thus, urban governments can introduce measures that encourage the use of renewable energy, such as providing financial incentives, tax breaks, and regulatory support Dilanchiev et al. (2023). Urban populations are more likely to be exposed to information about the benefits of renewable energy, leading to higher adoption rates. However, there are many challenges in implementing renewable energy projects in the urban areas. The variability of weather and time of day affects renewable energy sources, which creates difficulties in maintaining a stable grid and highlights the need for efficient energy storage solutions. Although renewable energy costs have dropped considerably, the initial investment required is still quite high. Renewable energy sources need to have a competitively leveled cost of electricity compared to fossil fuels. We must develop infrastructure like transmission networks and upgrade existing grids to transition to renewable energy. Public support and policies are necessary for renewable energy projects in urban areas. Successful implementation requires addressing challenges such as feedstock availability, land use conflicts, and emissions management Kolkowska (2023). To establish sustainable energy systems in cities, significant changes to the supply infrastructure are necessary, along with a comprehensive understanding of the entire supply chain.

The DCE model exhibits a political stability coefficient of 0.1563, whereas the corresponding value for the DCE-IV model is 0.12534. A direct correlation exists between REC and political stability. According to the DCE model, an increase of 10% in political stability corresponds to an estimated 1.563% rise in the REC. According to the DCE-IV model, a 10% improvement in political stability leads to a 1.2534% increase in the REC. Hence, concerning the anticipated effect on the REC, the DCE model proposes a significantly more pronounced consequence than the DCE-IV model. Additionally, research indicates that government interventions and the implementation of favorable regulations could encourage the use of renewable energy sources(Losada-Puente *et al.,* 2023; Mindia *et al.,* 2024; Nydrioti *et al.,* 2024; Qamaruzzaman, 2025). Countries with low political stability may face challenges in developing and adopting renewable energy technologies due to unclear national policies, insufficient incentives, and unrealistic government targets. In certain situations, having a stable political environment may not necessarily guarantee an increase in the use of renewable energy, particularly true in countries with overly complex administrative processes, so there may be less penetration of renewable energy. Moreover, the use of renewable energy can be hindered by geopolitical risks and a lack of clear national policies and incentives. Additionally, impractical government targets can delay the developing and adoption of renewable energy technologies. Therefore, although political stability can help promote renewable energy, other factors, such as administrative obstacles and inadequate policies, can impede its adoption.

Positive coefficients (0.14613 in the DCE model and 0.1385 in the DCE-IV model) suggest a positive correlation between trade openness and the demand for renewable energy. The adjusted R-squared value of the DCE model is marginally higher at 0.9439 than that of the DCE-IV model at 0.9234, indicating that the DCE model might have a slight edge in explaining variations in the REC. Assuming all other variables remain constant, the DCE model predicts that a 10% augmentation in trade openness would result in a 1.385% increase in the REC. Per the DCE-IV model, an increment of 1.4613% in the REC would result from a 10% rise in trade openness. Aligning with our findings, countries can enhance the growth and implementation of renewable energy technologies by importing advanced equipment, expertise, and technologies through open trade policies. Open trade policies can attract FDI in the renewable energy industry, bringing in the required funds and resources to grow and expand renewable energy projects. When countries engage in international trade, the price of renewable energy technologies has the potential to decrease, making them more economically viable (Zhang *et al.,* 2021). Participating in global trade can promote sharing of knowledge, skills, and technologies, leading to progress and developments in renewable energy technologies (Thi *et al.,* 2023). International trade can encourage collaboration between regions and the growth of regional energy markets. Thus, it can facilitate the incorporation of renewable energy sources into the overall energy supply (Yang *et al.,* 2022). On the contrary, many studies have also found the potential adverse effects of trade openness on renewable energy consumption. Greater trade openness can result in more competition from non-renewable energy sources, which could impede the expansion of renewable energy usage (Deng *et al.,* 2024; Feng *et al.,* 2024; Ghazouani et al., 2020; Guan[1] & Qamruzzaman, 2024). Trade openness can make domestic renewable energy sectors vulnerable to global market changes, impacting their investment and growth. It can also result in the growth of energy-intensive industries, increasing overall energy consumption, including non-renewable sources. Trade openness may require aligning policies with trading partners, potentially compromising domestic renewable energy policies and goals. Relying on imported renewable energy technologies due to trade openness can lead to dependence and hinder domestic innovation and industry development (Losada-Puente *et al.,* 2023; Zhang *et al.,* 2021).

The positive coefficient in the DCE model indicates that an increase in REC is directly proportional to a rise in FDI. On the other hand, the negative coefficient of the DCE-IV model implies that the REC decreases as FDI increases. According to the DCE model, an increase of 10% in Foreign Direct Investment (FDI) leads to a corresponding increase of 1.0891% in the Resource Efficiency Coefficient (REC). In contrast, the DCE-IV model predicts that an increase of 10% in FDI leads to a reduction of 7.0382% in the REC. Multiple studies provide substantial support for the positive correlation that exists between Foreign Direct Investment (FDI) and REC, such as (Adjei-Mantey & Adams, 2023; AMIR, 2023; LINK, 2023; Nydrioti *et al.,* 2024; Yang *et al.,* 2022). FDI can enhance the progress and acceptance of renewable energy technologies by providing cutting-edge apparatus, expertise, and knowledge from other nations. Foreign companies operating in the host country's markets can push domestic firms to become more competitive, resulting in the development of innovative renewable energy technologies.

FDI can bring in foreign investment into the renewable energy industry, which can help fund and support the growth of renewable energy projects. Renewable energy can positively affect the environment and overall quality of life, leading to a healthy environment and labor productivity. Furthermore, increasing labor productivity will attract FDI inflow. Renewable energy demand can decrease carbon dioxide emissions, and FDI can contribute to this by supporting the adoption of renewable energy technologies(Sebos et al., 2016). Although FDI is commonly linked to implementing energy-efficient technologies and encouraging renewable energy use, recent studies have suggested that there could be adverse consequences. These studies indicate that in certain situations, FDI might result in a decrease in renewable energy consumption. A recent study by Tariq *et al.* (2023) discovered that when foreign direct investment (FDI) increases by 1%, there is a corresponding decrease in renewable electricity consumption by 0.01%. Moreover, FDI can bring in energy-efficient methods that reduce renewable electricity consumption.

6. Conclusion and policy suggestion

6.1. Conclusion

This study explores the interplay between external debt, remittances, political stability, urbanization, and renewable energy consumption in BIMSTEC nations from 1995 to 2021. Employing advanced econometric techniques, including Dynamic Common Correlated Effects (DCE) and Instrumental Variable (DCE-IV) methods, the analysis reveals significant interdependencies among the examined factors, offering valuable insights for regional policy development. The findings highlight that external debt has a nuanced positive relationship with renewable energy consumption. While increased debt facilitates investment in clean energy infrastructure, overreliance on debt might strain fiscal stability. Remittances emerge as a pivotal factor, with their inflow enabling households to adopt renewable energy technologies, thus contributing to a sustainable energy transition. Similarly, urbanization positively influences renewable energy demand, reflecting the growing energy needs of expanding urban centers. Political stability plays a crucial role in fostering investor confidence and enabling consistent policy frameworks that encourage long-term investments in renewable energy. The study underscores BIMSTEC nations' need to harmonize economic development with sustainable energy practices. This requires targeted policies, such as incentivizing remittances for renewable energy projects, promoting urban planning that integrates green technologies, and leveraging external debt for clean energy investments under stringent monitoring mechanisms. Maintaining political stability and fostering regional cooperation is also pivotal to attracting foreign direct investments and achieving energy efficiency goals. This research emphasizes the importance of adopting comprehensive strategies that address the multifaceted determinants of renewable energy consumption. By aligning economic and environmental objectives, BIMSTEC nations can accelerate their progress toward sustainable development and significantly contribute to global climate goals. These insights provide a foundation for future research and policy formulation, ensuring a balanced approach to regional growth and sustainability.

6.2. Policy Implications

These findings guide the formulation of policies to fulfill the commitments made by these nations under the United Nations' Sustainable Development Goals (SDGs). The BIMSTEC governments must harmonize economic development, energy transition, and environmental policies. The governments of these nations should adopt a holistic approach that combines economic development, energy transition, and environmental policies. This will help them reduce their carbon intensity levels and promote sustainable economic growth by facilitating the transition to renewable energy.

In this regard, first, BIMSTEC countries should develop robust renewable energy policies that enhance energy literacy, improve infrastructure, and foster regional cooperation, which will optimize the utilization of natural resources and drive renewable energy development. The government should provide financial support for research and development in renewable energy technologies, which can be done through tax incentives, subsidies, or feed-in tariffs for businesses and individuals who adopt clean energy. It is also important to set ambitious yet attainable targets for renewable energy and implement regulations and policies that support its integration into the power grid. Public awareness campaigns, workshops, and training programs should also be conducted to educate communities about the benefits of renewable energy.

Second, there is a positive correlation between remittances and clean energy integration. BIMSTEC nations should leverage remittances to support the adoption of renewable energy technologies, which can be achieved by channeling remittances into clean energy projects, contributing to economic growth, poverty reduction, and sustainable development goals, which can be done by creating specific funds or financial tools that allow remittances to be directed toward clean energy projects, which can be done by establishing partnerships between financial institutions and renewable energy initiatives, making it easier for investments to be made. Additionally, offering incentives such as tax breaks or subsidies to households or businesses that receive remittances and invest in renewable energy technologies can encourage more people to choose sustainable options.

Third, urbanization has a significant impact on energy consumption. BIMSTEC countries need to address the rising energy demand associated with urbanization. Policies should focus on promoting energy efficiency, sustainable urban planning, and the adoption of renewable energy sources to meet the growing energy needs of urban areas. One way to improve construction practices is by implementing building codes prioritizing energy efficiency and sustainability. This means ensuring new buildings are designed and constructed to minimize energy consumption and environmental impact. Additionally, offering incentives for energy-efficient renovations in existing urban structures can encourage property owners to make sustainable upgrades. Another aspect of creating a greener city is promoting green transport options, which can be done by encouraging public transport, bicycles, and walking paths. Invest in electric vehicle infrastructure and incentivize their adoption by integrating innovative energy monitoring, waste management, and water conservation technologies. Develop green spaces and urban forestry to mitigate heat islands and reduce energy needs.

Fourth, BIMSTEC nations should prudently manage external debt to finance renewable energy projects. It is crucial to ensure that debt is used to support sustainable energy initiatives and avoid overreliance on debt, which can lead to financial vulnerabilities. It is essential to allocate external debt towards sustainable projects, particularly those related to renewable energy infrastructure, which can be achieved by negotiating favorable loan terms and interest rates for such initiatives. Additionally, it is crucial to diversify funding sources by exploring alternative financing options beyond debt, such as public-private partnerships or green bonds. Ensure transparent monitoring mechanisms for the effective utilization of borrowed funds.

Finally, BIMSTEC countries must focus on maintaining political stability and good governance to encourage investment in renewable energy. This would help build trust among investors and make it easier to attract long-term investments in renewable energy infrastructure and technologies. To promote renewable energy investments, it is vital to have clear and consistent policies in place. These policies should be transparent and provide certainty to investors, encouraging them to make long-term commitments. Collaboration between the public and private sectors and research institutions is crucial to drive innovation and investment in renewable energy. Additionally, efforts should be made to strengthen institutions by improving governance frameworks and regulatory environments and investing in capacity-building to attract and retain sustainable investments.

Declaration

Ethics approval and consent to participate
Not applicable

Consent for publication
Not applicable

Availability of data and materials
The datasets used and/or analyzed during the current study are available at 701 from the corresponding author upon reasonable request.

Competing interests
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