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Nexus between foreign direct investment, gross capital formation, financial development and renewable energy consumption: evidence from panel data estimation

Md. Qamruzzaman *

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

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Abstract

This research examines the correlation between foreign direct investment (FDI), gross capital formation (GCF), financial development, and renewable energy consumption (REC). The research utilizes the CS-ARDL and NARDL estimates to identify a strong and statistically significant connection, both in the long-term and short-term, between Foreign Direct Investment (FDI), Gross Capital Formation (GCF), financial development, and Regional Economic Cooperation (REC). More precisely, a 10% alteration in Foreign Direct Investment (FDI) leads to a 1.545% augmentation in Research and Development Expenditure (REC) over an extended period of time, and a 0.735% boost in the immediate term. Likewise, favorable (unfavorable) advancements in foreign direct investment (FDI) hasten (diminish) the pace of economic growth in the long term. The analysis also demonstrates a strong and statistically significant relationship between GCF and REC, highlighting the advantageous impact of domestic capital creation on the integration of clean energy. Moreover, it reveals a favorable correlation between financial development and REC, indicating that the financial incentives enabled by financial development have a crucial impact on encouraging the use of renewable energy. These results are consistent with previous research and have important consequences for the connection between foreign direct investment (FDI), gross capital formation (GCF), financial development, and sustainable energy. Nonetheless, the study highlights the importance of taking into account the nature and caliber of foreign direct investment (FDI) inflows, the influence of fair and sustainable growth in the renewable energy sector on the environment and society, and the possible environmental and social consequences of renewable energy projects fueled by domestic capital expansion. Furthermore, it emphasizes the need of well-rounded policy frameworks and governance mechanisms to guarantee that foreign direct investment (FDI), green climate fund (GCF), and financial development effectively contribute to equitable and sustainable growth in the consumption of renewable energy. The study's findings offer valuable insights on how to effectively use foreign direct investment (FDI), global climate finance (GCF), and financial development to increase the use of renewable energy. However, it also emphasizes the importance of carefully evaluating the wider consequences and related factors in order to develop sustainable strategies for promoting renewable energy consumption.

Keywords: Renewable energy consumption; FDi; GCF; financial development; CS-ARDL; NARDL

1. Introduction

Renewable energy use in lower-income countries is not given high importance owing to their limited investment capacity, resulting in reliance on conventional energy sources[1]. Nevertheless, advancements in renewable energy and energy storage have significantly reduced expenses in economically disadvantaged nations. It is essential to use these technologies to tap into the potential of emerging countries and accomplish worldwide objectives [2, 3]. Developing nations possess ample renewable energy resources such as solar energy, wind power, geothermal energy, and biomass. By harnessing these energy sources, they may diminish their reliance on oil and establish energy portfolios that are less

* Corresponding author: Md. Qamruzzaman

susceptible to price escalations. The incorporation of sustainable energy sources will also have a pivotal impact in mitigating wealth disparity. Low-income communities and nations are disproportionately impacted by the increasing energy prices. Therefore, it is crucial to provide low-income assistance throughout this energy transition to give them with financial support[4, 5]. The issues associated with transitioning to renewable infrastructure are of great significance, and it is projected that global energy consumption will continue to rise by 1%-2% per year [6, 7].

Using renewable energy is crucial in order to support sustainable development, guarantee energy security, and improve social well-being [8-16]. RE provides a wide array of advantages that are crucial for both the economic and social aspects of society. When it comes to the economy, the use and development of renewable energy sources have the potential to bring about significant positive outcomes. Investments in renewable energy have the power to greatly boost economic growth by generating a multitude of job opportunities across different sectors like manufacturing, installation, research and development, and production. In the stud of Wang, et al. [17], Su, et al. [18], Rahman, et al. [19], Olabi and Abdelkareem [20] disclosed the potential to greatly enhance economic growth at both the local and national levels, especially in regions that are fortunate to have abundant renewable energy resources. In addition, the use of renewable energy technologies offers the potential to lower energy expenses for both consumers and companies over time[21-23]. RE can have a great impact on the economy, bringing about lower monthly energy expenses and making energy more affordable for everyone. Renewable energy offers a promising solution to bolster energy security by decreasing our dependence on fossil fuels and diversifying our energy sources. This can help decrease the potential risks associated with price fluctuations and supply disruptions. At the same time, it's crucial to recognize the immense value of renewable energy and the positive effects it has on society. By embracing renewable energy technology, we can make a positive impact on public health by decreasing the levels of air and water pollution that are typically linked to conventional energy sources. This has the potential to bring about cost savings in healthcare and improve the overall well-being of communities, especially in areas heavily affected by pollution from traditional energy sources.

Renewable energy projects also have the potential to empower local people by opening doors to ownership, participation, and profit sharing. People may find common ground and a renewed feeling of agency via community-based renewable energy initiatives. Additionally, these initiatives may strengthen and stimulate the local economy. In addition to improving the area's quality of life, these projects provide residents a greater feeling of pride in their neighborhood. Renewable energy technology also has the potential to level the playing field by making electricity more accessible, particularly in remote or underdeveloped places. An amazing chance to provide communities with reliable and environmentally friendly energy exists with renewable energy alternatives that do not rely on centralized power networks, such as solar home systems and mini-grids. The economy and people's level of life might both benefit from this. There are many reasons why renewable energy is so crucial to the economy and to society as a whole. The list of possible benefits is long and includes an uptick in the economy, new jobs, reduced energy prices, better public health, more energy independence, community support, and more energy availability. Recognizing and capitalizing on the economic and social benefits that come with this transition is crucial if we are to achieve a more equitable and sustainable energy future.

The nexus between foreign direct investment (FDI), gross capital formation, financial development, and renewable energy consumption is a topic of increasing interest and importance in the context of global economic development and sustainability. These factors are interconnected in complex ways, and understanding their relationships is crucial for shaping policies and strategies that promote both economic growth and environmental responsibility [24-28]. Foreign direct investment represents a significant inflow of capital and technology into a country, often playing a key role in economic development. Gross capital formation, on the other hand, reflects the level of investment in physical assets within an economy, which is essential for driving productivity and growth. Financial development, encompassing the efficiency and effectiveness of financial intermediaries and markets, is crucial for facilitating investment and economic activity. Meanwhile, renewable energy consumption is a vital indicator of a country's commitment to sustainable and environmentally friendly energy sources, with implications for climate change mitigation and energy security. Studying the interplay between these factors can provide valuable insights into how FDI, capital formation, financial development, and renewable energy consumption influence each other and contribute to overall economic and environmental outcomes. This understanding can inform policies and strategies aimed at promoting sustainable economic growth, energy transition, and environmental stewardship. By examining the nexus between these variables, researchers and policymakers can gain a deeper understanding of how to harness FDI, capital formation, and financial development to drive renewable energy consumption and sustainable development. This knowledge can help guide decision-making processes and shape initiatives that balance economic prosperity with environmental sustainability, ultimately contributing to a more resilient and equitable global economy.

2. Literature review

2.1. FDI effects on renewable energy consumption

FDI is widely recognized as a crucial factor in the economic development and transfer of technology to the countries where it is received [27-32]. There is a growing body of study that examines the impact of foreign direct investment (FDI) on the use of renewable energy sources, reflecting the increasing importance of these sources in the global economy. Both developed and developing nations have been the focus of studies investigating the correlation between foreign direct investment and the adoption of renewable energy sources. Consensus findings suggest that foreign direct investment (FDI) may assist host countries in developing their renewable energy infrastructure and technology capacities. This is often attributed to the fact that multinational corporations involved in renewable energy initiatives disseminate knowledge, expertise, and funding [33-38]. Literature offered by Chau, et al. [39], Cao, et al. [40], Binh An, et al. [41], Balsalobre-Lorente, et al. [42] indicate that foreign direct investment (FDI) has a positive impact on the renewable energy policies and frameworks of host countries. The regulatory frameworks and investment climates for renewable energy are vulnerable to the impact of multinational firms, who often bring with them their own national standards and optimal approaches when they participate in such ventures.

In the Studies of Qamruzzaman [9], Su, Wang, Li and Wang [18], Rahman, Alam and Velayutham [19], Zhao and Qamruzzaman [43] have shown that foreign direct investment (FDI) plays a crucial role in driving innovation and technical advancement within the renewable energy industry. Foreign direct investment (FDI) may facilitate the adoption of renewable energy in host countries via the transfer of advanced renewable energy technologies, research and development initiatives, and the dissemination of information. However, it is worth mentioning that the literature acknowledges the existence of potential limitations and challenges associated with foreign direct investment (FDI) in the renewable energy sector. Concerns arise over the potential for foreign direct investment (FDI) to foster dependence on certain technologies, create imbalances in the distribution of advantages, and generate adverse environmental consequences via large-scale renewable energy initiatives. Furthermore, the impact of foreign direct investment (FDI) on the use of renewable energy sources such as solar, wind, hydropower, and biofuels may exhibit some degree of fluctuation. Studies of Derindag, Maydybura, Kalra, Wong and Chang [6], Chen and Raza [7], Xiao and Qamruzzaman [44], JinRu, et al. [45] have examined the impact of foreign direct investment (FDI) on the use of renewable energy in various sectors, uncovering the unique dynamics and challenges associated with each kind of renewable power. The study of Chen and Raza [7], Karim, et al. [46], Farzana, et al. [47] the consequences of foreign direct investment (FDI) on the use of renewable energy sources reveals that this relationship is intricate. Considering the potential challenges and industry-specific factors when using foreign direct investment (FDI) for sustainable energy expansion is of utmost importance, notwithstanding the potential benefits of FDI in boosting renewable energy consumption via investment, innovation, and knowledge exchange. Additional research is necessary to get a deeper understanding of the impact of foreign direct investment (FDI) on the use of renewable energy sources. This research will help inform strategies and policies that may maximize the positive benefits of FDI on the transition to sustainable energy.

2.2. Gross capital formation effects on renewable energy consumption

Considering the growing consensus on the significance of investment in facilitating the adoption of renewable energy, numerous studies have examined the correlation between GDP growth and the utilization of renewable energy [30, 48]. A comprehensive analysis has been carried out to investigate the influence of gross capital development on the utilization of renewable energy in both developed and developing nations. In line with previous research, our findings demonstrate that the utilization and adoption of renewable energy sources are more pronounced in the presence of heightened investments in physical assets and infrastructure, as indicated by gross capital creation. The investment in the essential infrastructure for the generation, transmission, and distribution of renewable energy is widely considered to play a significant role in this correlation. Furthermore, extensive research has demonstrated that the generation of significant revenue plays a pivotal role in promoting innovation and technological progress within the renewable energy industry. Empirical data supports the notion that greater investment in research and development, coupled with the adoption of cutting-edge technology, can significantly improve the utilization of renewable energy sources. Investing in the development of renewable energy infrastructure has the potential to greatly improve the accessibility of sustainable and eco-friendly energy, especially in developing nations [43, 44, 49].

In addition, various studies such as Bhuiyan, Zhang, Khare, Mikhaylov, Pinter and Huang [3], Qamruzzaman [11, 12], Wang, Qamruzzaman, Serfraz and Theivanayaki [25], JinRu, Qamruzzaman, Hangyu and Kler [45], Wei, et al. [50], Guan and Qamruzzaman [51] have analyzed the effects of different types of investment, encompassing both public and private sectors, on the utilization of renewable energy sources. There is a growing body of evidence indicating that investments in renewable energy projects and infrastructure, regardless of whether they are carried out by the public sector or private companies, can have a significant impact on the development and adoption of renewable energy technologies. The study recognizes numerous limitations and possible difficulties in establishing a causal relationship between GCF and the use of RE. There are significant concerns regarding the lack of appropriate regulatory structures, market incentives, and policy frameworks that are necessary to ensure that the generation of capital leads to equitable and sustainable growth in the adoption of renewable energy[52-54]. Studies examining the correlation between gross capital formation and renewable energy consumption highlight the pivotal importance of investment in propelling the shift towards renewable energy sources. Increased investment in renewable energy leads to higher utilization, but the impact of this investment is susceptible to political, regulatory, and market forces. As a result, it is crucial to approach this matter with utmost caution and thoughtful analysis. Further research is required to gain a more comprehensive understanding of the effects of gross capital development on renewable energy consumption. This will assist in the development of informed policies and legislation that optimize investments in sustainable energy transitions.

2.3. Financial development effects on renewable energy consumption

There has been a notable increase in the volume of research dedicated to exploring the correlation between the expansion of the financial sector and the utilization of renewable energy sources [43, 47, 55-57]. This can be attributed to the increasing recognition of the crucial role that financial institutions play in facilitating the shift towards sustainable energy sources. The aim of this literature review is to offer a succinct overview of the key findings and commonly observed patterns in research exploring the impact of economic growth on the adoption of renewable energy sources. Extensive research has been conducted in both developed and developing nations to explore the correlation between economic prosperity and the adoption of renewable energy sources. Previous research such as Tan, Qamruzzaman and Karim [27], Qamruzzaman and Kler [29], Farzana, Qamruzzaman, Islam and Mindia [47], Akpanke, et al. [58], MEHTA, et al. [59], Qamruzzaman and Karim [60] has shown that a strong and well-established financial system is closely linked to higher levels of investment and the widespread adoption of renewable energy technology. This observation aligns with the results of other research studies. This system is characterized by efficient financial intermediation, convenient access to capital, and a regulatory framework that is supportive. The significant role played by financial institutions in enabling investment opportunities, offering risk management solutions, and providing funding for renewable energy projects may be the key factor driving the increased adoption of renewable energy.

Existing literature highlights the importance of market mechanisms and financial innovation in promoting the adoption of renewable energy sources. Based on various studies, it has been found that certain financial products, such as green bonds, renewable energy funds, and carbon finance instruments, can effectively attract investments in sustainable energy sources and generate profits for renewable energy projects[26, 50, 57]. If there are laws in place that promote the expansion of renewable energy projects, such as feed-in tariffs, tax incentives, and renewable energy objectives, then financial institutions may be more inclined to actively engage in these projects. In addition, various studies have been carried out to enhance the utilization of renewable energy sources. These studies have explored the potential advantages that developing nations may experience through improved access to finance and initiatives promoting financial inclusiveness. When individuals, businesses, and communities have convenient access to financial services like loans, insurance, and investment opportunities, they can potentially improve their utilization of renewable energy sources by investing in the necessary technology and infrastructure[1, 46, 47, 56]. Additionaly, The existing literature has acknowledges that there are numerous limitations and challenges associated with the connection between economic growth and the utilization of renewable energy sources. The insufficient level of transparency in financial markets, risk management systems, and regulatory frameworks has raised significant concerns. The absence of transparency may hinder the capacity of financial development to facilitate sustainable and fair growth in the production and utilization of renewable energy [49, 61-65].

Ultimately, studies that assess the influence of financial development on the adoption of renewable energy sources underscore the significance of robust financial systems in facilitating the shift towards sustainable energy. To effectively raise funds, mitigate risks, and foster investment in renewable energy, it is crucial to establish a strong financial system characterized by inclusivity, innovation, and supportive regulation. Further study is necessary to gain a deeper understanding of how increases in financial development impact the utilization of renewable energy. This information will greatly enhance the development of plans and policies aimed at maximizing the positive impact of financial systems on the transition to sustainable energy.

3. Data and methodology of the study

To explore the magnitude of financial openness and trade openness on energy transition, the present study has implemented several robust econometric tools such as Cross-sectional ARDL offered by [66]. The generalized CS-ARDL for the empirical testing is as follows.

$$\overline{REC}_{it} = \bar{\alpha}_{it} + \sum_{j=1}^{p} \bar{\beta}_{ij} \overline{REC}_{i,t-j} + \sum_{j=0}^{q} \bar{\gamma}_{ij} \bar{Q}_{i,t-j} + \bar{\omega}_t' P_t + \bar{\epsilon}_{it} \ (6)$$

Where, $\bar{\alpha}_{it} = \frac{\sum_{i-1}^{N} \alpha_i}{N}$

$$\overline{REC}_{t-j} = \frac{\sum_i^N REC_{i,,t-j}}{N},\ \bar{\beta}_j = \frac{\sum_i^N \beta_{i,j}}{N}\quad j = 0{,}1{,}2\ p$$

$$\bar{Q}_{t-j} = \frac{\sum_i^N Q_{i,,t-j}}{N}, \bar{\Upsilon}_j = \frac{\sum_i^N \Upsilon_{i,j}}{N}, J = 0{,}1{,}2\ q$$

$$\bar{\bar{\omega}}_j = \frac{\sum_{i=1}^{N} \omega_i}{N}, \bar{\varepsilon}_t = \frac{\sum_i^N \epsilon_{i,t}}{N}$$

The error term, εi, in Eq. (6) is independently distributed across time and countries, mean congregates to zero (i.e., $\bar{\varepsilon} t$ = 0) in root mean square error as $N \rightarrow \infty$. Therefore, the linear effects of both dependent and independents can establish in the presence of cross-sectional dependence in μi,

$$REC_{it} = \bar{\alpha}_{it} + \sum_{j=1}^{p} \bar{\beta}_{ij} \overline{REC}_{i,t-j} + \sum_{j=0}^{q} \bar{\gamma}_{ij} \bar{Q}_{i,t-j} + \bar{\omega}_t' P_t \ \ldots .(7)$$

$$\downarrow$$

$$\bar{\omega}_t' P_t = \overline{REC}_{it} - \bar{\alpha}_{it} + \sum_{j=1}^{p} \bar{\beta}_{ij} \overline{REC}_{i,t-j} + \sum_{j=0}^{q} \bar{\gamma}_{ij} \bar{Q}_{i,t-j}$$

$$\downarrow$$

$$P_t = \frac{\overline{REC}_{it} - \bar{\alpha}_{it} + \sum_{j=1}^{p} \bar{\beta}_{ij} \overline{REC}_{i,t-j} + \sum_{j=0}^{q} \bar{\gamma}_{ij} \bar{Q}_{i,t-j}}{\bar{\omega}_t'}$$

Thus, the Panel CS-ARDL specification of Equation (2)

$$\overline{REC}_{it} = \epsilon_{it} + \sum_{j=1}^{p} \beta_{ij} \overline{REC}_{i,t-j} + \sum_{j=0}^{q} \gamma_{ij} \bar{Q}_{i,t-j} + \sum_{j=0}^{p} \bar{\partial}_{tj}' \bar{P}_{i,t-j} + \epsilon_{it} \ \ldots .(8)$$

Where $\bar{P} = (\overline{FDI}, \bar{X})$ and $S_{\bar{Z}}$ In the number of lagged cross-sectional averages. Furthermore, Equation (8) can be reparametrized to the effects of the ECM presentation of Panel CS-ARDL as follows:

$$\Delta REC_{it} = \alpha_i + \xi_i (REC_{it-1} - \omega_t' Q_{it-1}) + \sum_{J=1}^{M-1} \gamma_{iJ} \Delta REC_{it-J} + \sum_{J=0}^{N-1} \beta_{ij} \Delta Q_{it-J} + \sum_{j=1}^{p} \lambda_j \overline{\Delta REC}_{i,t-j} + \sum_{j=0}^{q} \delta_j \overline{\Delta Q}_{i,t-j} + \sum_{j=0}^{S_{\bar{Z}}} \bar{\partial}_{tj}' \bar{P}_{i,t-j} + \mu_{it} \ \ldots .(9)$$

Where $\overline{\Delta REC}_{t-j} = \frac{\sum_i^N \Delta REC_{i,,t-j}}{N}, \overline{\Delta Q}_{t-j} = \frac{\sum_i^N \Delta Q_{i,,t-j}}{N}$

Asymmetric ARDL following the nonlinear framework introduced by [67], the above equation (1-3) can be established in the following manner

$$REC_t = (\beta^+ FDI^+_{1,t} + \beta^- FDI^-_{1,t}) + (\gamma^+ FD^+_{1,t} + \gamma^- FD^-_{1,t}) + (\pi^+ GCF^+_{1,t} + \pi^- GCF^-_{1,t}) + \delta_i X_t + \varepsilon_t \text{ ......(10)}$$

Where the value of $\beta^+ \& \beta^-$; $\gamma^+ \& \gamma^-$; $\pi^+ \& \pi^-$ Stands the asymmetric elasticity of financial, trade, and economic openness on REC, NRE, and fossil energy consumption, respectively. The asymmetric decomposition of financial openness $[FO^+_{1,t};\ FO^-_{1,t}]$, Trade Openness $[TO^+_{1,t};\ TO^-_{1,t}]$, and Economic Openness $[EO^+_{1,t};\ EO^-_{1,t}]$ can be derived through the execution of the following equations.

$$\begin{cases} POS(FDI)_{1,t} = \sum_{k=1}^{R} lnFDI^+_k = \sum_{K=1}^{R} MAX(\Delta lnFDI_k, 0) \\ NEG(FDI)_t = \sum_{k=1}^{R} lnFDI^-_k = \sum_{K=1}^{R} MIN(\Delta lnFDI_k, 0) \end{cases} : \begin{matrix} POS(FD)_{1,t} = \sum_{k=1}^{R} lnFD^+_k = \sum_{K=1}^{R} MAX(\Delta lnFD_k, 0) \\ NEG(FD)_t = \sum_{k=1}^{R} lnFD^-_k = \sum_{K=1}^{R} MIN(\Delta lnF_k, 0) \end{matrix}$$

$$; \begin{matrix} POS(GCF)_{1,t} = \sum_{k=1}^{R} lnGCF^+_k = \sum_{K=1}^{R} MAX(\Delta lnGCF_k, 0) \\ NEG(GCF)_t = \sum_{k=1}^{R} lnGCF^-_k = \sum_{K=1}^{R} MIN(\Delta lnGCF_k, 0) \end{matrix}$$

Now, equation (14) is transformed into asymmetric long-run and short-run coefficient assessment as follows:

$$\begin{aligned} \Delta REC_t = {} & \partial \text{U}_{t-1} + (\mu^+ FDI^+_{1,t-1} + \mu^- FFDIO^-_{1,t-1}) + (\alpha^+ FD^+_{1,t-1} + \alpha^- FD^-_{1,t-1}) + (\varphi^+ GCF^+_{1,t-1} + \varphi^- gcf^-_{1,t-1}) + \beta X^*_{1,t-1} \\ & + \sum_{j=1}^{m-1} \beta_j \Delta REC_{t-j} \ {}_0 + \sum_{j=1}^{n-1} (\epsilon^+ \Delta FDI^+_{1,t-1} + \epsilon^- \Delta FDI^-_{1,t-1}) + \sum_{j=0}^{m-1} (\theta^+ \Delta FD^+_{1,t-1} + \theta^- \Delta FD^-_{1,t-1}) \\ & + \sum_{j=0}^{m-1} (\vartheta^+ \Delta GCF^+_{1,t-1} + \vartheta^- \Delta GCF^-_{1,t-1}) + \sum_{j=0}^{m-1} \mu \Delta X^*_{1,t-1} + \varepsilon_t .. (13) \end{aligned}$$

Moreover, the directional association established through the implementation of Period to execute the target estimation, the study has performed several preliminary assessments, that is, slop of homogeneity test following [68], cross–sectional dependency test targeting the framework offered by [69-71]. The test statistic is to be derived by executing the following equations.

$$y_{it} = \alpha_i + \beta_i x_{it} + u_{it} \quad \text{i= 1......N, t=1......T ....(16)}$$

$$LM = T \sum_{I=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{IJ \underset{d}{\rightarrow} X^2 N(N+1)2} \text{ ......(3)}$$

$$CD_{lm} = \sqrt{\frac{N}{N(N-1)}} \sum_{I=1}^{N-1} \sum_{J=i+1}^{N} \left(T \hat{\rho}_{ij} - 1\right) \text{ ....(17)}$$

$$CD_{lm} = \sqrt{\frac{2T}{N(N-1)}} \sum_{I=1}^{N-1} \sum_{J=i+1}^{N} \left(\hat{\rho}_{ij}\right) \text{ ....(18)}$$

$$CD_{lm} = \sqrt{\frac{2}{N(N-1)}} \sum_{I=1}^{N-1} \sum_{J=i+1}^{N} \left(\frac{(T-K)\hat{\rho}^2_{ij} - u_{Tij}}{v^2_{Tij}}\right) \vec{d}\,(N, 0) \text{ ....(19)}$$

The static properties have been investigated by implementing the second-generation panel unit root test introduced by Pesaran [72], which commonly experiences the robustness and superior performance of the widely adopted second-generation panel unit root test, CIPS and CADF. Researchers and practitioners alike have found this test to be the ultimate solution, surpassing traditional tests. Introducing the Cross-sectionally Augmented IPS (CIPS) test - the perfect solution for analyzing non-stationary time series with spatial correlation. Its unique ability to consider cross-sectional dependence within a panel data structure sets it apart. Introducing the Common Correlated Effects Average Dickey-

Fuller (CADF) test - the ultimate solution to the limitations of standard unit root tests when identifying stationarity in panels with common shocks. Whether the study deals with small sample sizes or unbalanced panels, both tests deliver reliable results that are frequently encountered in empirical studies. With the added benefit of accommodating diverse individual-specific trends and intercepts, these models maintain exceptional power in the face of various forms of serial correlation commonly found in economic time series data. The following equation is to be implemented for deriving the test statistics.

This approach is known as CADF. Pesaran (2007) uses equation-9 for the CADF unit root test:

$$\Delta Y_{it} = \beta_i + \gamma_i y_{i,t-1} + \pi_i \bar{y}_{t-1} + \beta_i \bar{y}_t + \rho_{it} \;\dots\dots (20)$$

$$\Delta Y_{it} = \mu_i + \gamma_i y_{i,t-1} + \pi_i \bar{y}_{t-1} + \sum_{k=1}^{p} \beta_{ik} \Delta y_{i,k-1} + \sum_{k=0}^{p} \beta_{ik} \overline{\Delta y}_{i,k-0} + \alpha_{it} \;\dots.(21)$$

$$CIPS = N^{-1} \sum_{i-1}^{N} \partial_i(N,T) \;\dots\dots..(22)$$

$$CIPS = N^{-1} \sum_{i-1}^{N} CADF \;\dots\dots (23)$$

The present study confirms the robustness estimation by employing the AMG and CCEMG; both methods can address the issue of CDS and heterogeneity ([29, 46, 73]

4. Interpretation and discussion

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' elementary characteristics. **Error! Reference source not found.** 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

Table 1 Results of cross-sectional dependency test

	(Breusch and Pagan 1980)	Pesaran (2004)	Pesaran, Ullah et al. (2008)	Pesaran (2006)
REC	2402.057***	71.488***	160.904***	35.121***
FDI	1243.847***	75.803***	148.183***	100.086***
FD	1843.589***	47.108***	213.622***	25.187***
GCF	628.347***	136.113***	70.018***	43.458***
Y	2084.044***	124.681***	60.112***	70.854***

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 **Error! Reference source not found.**. According to test statistics found from CIPS and CADF with a level, all eh variables are nonstationary, while the first difference operator established stationary by rejecting the null hypothesis of stationary.

Table 2 Results of second generation panel unit root test

	CIPS		CADF		CADF			
	At level		Δ		At level		Δ	
	C	C&T	C	C&T	C	C&T	C	C&T
REC	-1.859	-3.388***	-1.1	-4.628***	-1.471	-2.581***	-2.315	-2.976***
FDI	-2.587	-5.272***	-2.516	-6.32***	-1.261	-4.897***	-1.876	-5.722***
FD	-1.753	-3.38***	-1.889	-2.387***	-2.558	-6.986***	-2.158	-4.198***
GCF	-1.678	-6.914***	-1.079	-5.712***	-1.741	-4.902***	-1.151	-3.323***
Y	-2.153	-2.659***	-2	-4.424***	-2.511	-7.614***	-2.83	-7.946***

Next, the survey executed a panel cointegration test by following the framework proposed in assessing the long-run association between energy consumption measured by renewable, fossil and bias and the explanatory variables. Based on a diverse proxy for dependent variables, the study performed three cointegration models for long-run assessment. The results of long-run cointegration are exhibited in **Error! Reference source not found.**, consisting of three panels of output. The test statistics derived from the panel cointegration test were found statistically significant at a 1% level, indicating the rejection of the null hypothesis of no-cointegration, alternatively revealing the long-run association between explained and explanatory variables.

Table 3 Results of panel cointegration test

Model	**FDI--->EC**	**FDI--->GG**	**FDI--->ED**	**FDI--->ER**
Gt	-15.674***	-11.114***	-9.315***	-7.077***
Ga	-10.338***	-15.931***	-15.809***	-13.244***
Pt	-11.897***	-4.165***	-14.766***	-7.694***
Pa	-14.948***	-11.361***	-12.247***	-12.478***
KRCPT				
MDF	-4.798***	12.451***	-4.765***	1.895***
DF	3.82***	-4.322***	12.893***	-2.683***
ADF	18.214***	-6.073***	-5.234***	13.254***
UMDF	11.817***	-3.623***	11.789***	7.257***
UDF	21.932***	19.592***	-6.976***	12.684***
PCT				
MDF	8.768***	1.108***	-3.661***	8.161***
PP	9.571***	5.04***	6.662***	-1.5***
ADF	8.398***	8.073***	13.83***	13.343***

For FDI, study revealed a positive and statistically significant linkage in the long-run (short run) between foreign direct investment and renewable energy consumption, which is valid both in the estimation of CS-ARDL and NARDL. Our findings is in line with existing literature see for instance [11, 33, 34, 74-81]. In particular, a 10% changes in the long-run (short) will results in increase o REC by 1.545% (0.735%). furthermore, the positive (negative) innovation in FDI results in acceleration (degradation) of REC in the long-run by 0.2763% (0.2669%) and by 0.0948% (0.0548%) with a 1% changes in the FDI inflow in the economy. In line with the findings of the CS-ARDL and NARDL models, the study discovered a significant and positive correlation between foreign direct investment (FDI) and the consumption of renewable energy, both in the short and long term. This discovery holds significant implications for the intricate relationship between foreign direct investment (FDI) and the development of sustainable energy [45, 82-86]. There is a robust and statistically significant relationship between foreign direct investment (FDI) and the consumption of renewable energy sources. This suggests that FDI plays a significant role in promoting and facilitating the adoption of renewable energy. The advancement and expansion of renewable energy infrastructure and technologies depend on the financial investment, technological expertise, and knowledge brought by foreign direct investment (FDI). This aligns with the notion that foreign direct investment has the potential to bring about these positive outcomes.

While these findings are certainly significant, it is important to thoroughly evaluate the study's constraints and broader ramifications. It is crucial to take into account the type and quality of foreign direct investment (FDI) inflows. This is because not all FDI has an equal impact on the development of sustainable energy. It is important to consider that foreign direct investment (FDI) can have varying effects on renewable energy consumption, depending on the location and other factors. To ensure that FDI contributes to fair and sustainable growth in renewable energy consumption, it is crucial to establish a comprehensive set of policies and governance measures [30, 50, 58, 87-89].

In addition, it is important for the research to consider the potential impact of equitable and sustainable growth in the renewable energy industry on both the environment and society. Furthermore, it is crucial to examine how foreign direct investment (FDI)-driven renewable energy projects could potentially influence these aspects. In order to enhance sustainability, it is imperative to ensure that the positive relationship between foreign direct investment and the utilization of renewable energy sources effectively benefits local communities. Ultimately, the study's discovery of a noteworthy and statistically meaningful connection between foreign direct investment (FDI) and renewable energy (RE) consumption is certainly commendable. However, to effectively formulate sustainable strategies for leveraging FDI to enhance the utilization of renewable energy, it is crucial to thoroughly assess the broader implications and associated factors that arise from these findings [51, 90-93].

The coefficients of gross capital formation on REC has revealed positive and statistically significant in both CS-ARDL and NARDL estimation in the long-run and short-run, implying a beneficial effects of domestic capital formation in inclusion of clean energy in the energy mix. Existing literature has supported our findings see for instance [59, 94-98]. The study's results emphasize the robust and significant correlation between gross capital formation (GCF) and renewable energy consumption (REC). The findings, derived from rigorous CS-ARDL and NARDL calculations, demonstrate that domestic capital creation significantly contributes to the integration of clean energy sources into the overall energy mix. These findings indicate that allocating resources towards renewable energy infrastructure might have favorable and enduring outcomes in terms of sustainable energy use. This finding underscores the need of allocating resources towards tangible assets and infrastructure in order to foster the adoption of sustainable energy sources. The premise is that more investment in infrastructure and technology correlates with increased acceptance and usage of renewable energy sources. However, it is essential to carefully assess the broader consequences and potential constraints associated with the research, regardless of the importance of these results. Considering the quality and distribution of domestic capital creation, as well as the efficacy of investing in renewable energy infrastructure, is crucial. Furthermore, it is crucial for the research to consider the potential disparities in how GCF impacts the use of renewable energy in different economic sectors and geographical areas. It is essential to acknowledge the significance of comprehensive policy frameworks and governance systems in guaranteeing that the investment in renewable energy results in sustainable and equitable development [99-104].

Furthermore, it is crucial for the research to include the potential environmental and social impacts of renewable energy projects that are motivated by domestic capital development. It is essential to give priority to inclusive and sustainable growth in the renewable energy industry. Ensuring that the positive factors of the greatest common factor (GCF) in renewable energy use lead to tangible benefits for local communities and contribute to wider sustainability goals is of utmost importance. The study's results highlight the significant and relevant correlation between GCF and the usage of renewable energy, which has great importance. Nevertheless, it is important to meticulously examine the broader ramifications and variables associated with these findings. This research aims to establish comprehensive and enduring strategies for leveraging domestic resources to promote the adoption of renewable energy [60, 105-110].

For financial development, the coefficients disclosed positively connected to REC in both CS-AEDL and NARDL estimation in the long-run and short-run assessment, suggestion the access to financial benefits that is financial development prompt the energy consumption especially renewable sources. Our results is in line with existing literature such as [14, 77, 93, 111-115]. According to the findings of the study, there is a significant and robust correlation between the utilization of renewable energy and financial development. Using the CS-ARDL and NARDL estimations, both the short-term and long-term analyses provide support for this conclusion. The findings of this study indicate that the provision of financial incentives, facilitated by financial development, is a pivotal factor in encouraging the use of energy sources, particularly renewable ones. While the implications of these results are noteworthy, it is imperative to thoroughly assess the broader ramifications and potential constraints associated with the research. An instance of this is the significance of considering the efficacy of financial systems in providing access to capital, risk management tools, and investment opportunities for renewable energy initiatives, in addition to the character and inclusiveness of financial development. Furthermore, it is critical that the study consider potential variations in the manner in which financial development influences the utilization of renewable energy across different economic sectors and regions. To ensure that financial development results in an inclusive and sustainable increase in the consumption of renewable energy, it is also vital to consider the significance of comprehensive policy frameworks and governance mechanisms.

Furthermore, the study must consider the potential environmental and social repercussions that may result from the financial development of renewable energy initiatives. Furthermore, it is imperative to emphasize the significance of sustainable and inclusive development in the renewable energy industry. Ensuring that the robust correlation between financial development and the utilization of renewable energy sources yields concrete benefits for local communities and advances broader sustainability goals is of the utmost importance. The study's conclusions regarding the robust and significant correlation between financial development and the adoption of renewable energy sources are, in the end, crucial. Nevertheless, it is imperative to conduct a comprehensive assessment of the broader ramifications and variables associated with these findings to formulate sustainable and all-encompassing strategies for leveraging financial progress to promote the adoption of renewable energy[110, 116-120].

Table 4 Results of Long –run and short-run coefficients: CS-ARDL and NARDL

Variables	**Coefficient**	**st.error**	**t-stat**		**Coefficient**	**st.error**	**t-stat**
Y	0.186	0.0721	2.5797	FDI	0.1545	0.0295	5.2372
Y^2	-0.2757	0.0451	-6.113	GCF	0.2241	0.0635	3.5291
FDI^+	0.2763	0.0348	7.9396	FD	0.1858	0.0215	8.6418
FDI	0.2669	0.0279	9.5663	Y	0.1651	0.0836	1.9748
FD^+	0.2805	0.0664	4.2243	Y2	0.2103	0.0348	6.0431
FD^-	0.2818	0.0152	18.5394				
GCF^+	0.2422	0.0384	6.3072				
GCF-	0.2647	0.0175	15.1257				
C	-0.1668	0.0669	-2.4932		-0.1217	0.0687	-1.7714
W_{FDI}	6.6943						
W_{FD}	11.9122						
W_{GCF}	8.237						
Y^2	0.0869	0.0572	1.5192	FDI	0.0735	0.0223	3.295964
FDI^+	0.1014	0.0343	2.9562	GCF	0.0689	0.0843	0.817319
FDI	0.0948	0.0312	3.058	FD	0.0564	0.0522	1.08046
FD^+	0.0548	0.0231	2.1995	Y	0.0843	0.0654	1.288991
FD^-	0.08	0.0128	6.25	Y2	0.0519	0.0505	1.027723
GCF^+	0.0738	0.0405	1.8222				
GCF-	0.0731	0.0475	1.5389				
Y^2	0.0667	0.0806	0.8275				
cointEq (-1)	0.0982	0.0602	1.6312				
W_{FDI}	7.0224						
W_{FD}	8.0575						
W_{GCF}	1.3215						

Table 5 displayed the results of directional causality test following the non-granger causality test. Study findings exposed bidirectional causality between REC, FD, GCF and Y, while unidirectional causality revealed from REC to FDI.

Table 5 Results of no granger causality test: D-H causality test

Null Hypothesis:	W-Stat.	Zbar-Stat.	remarks	Causal effects
REC does not homogeneously cause FDI	2.698193	2.843896	<--	Unidirectional
FDI does not homogeneously cause REC	5.25186	5.53546		
REC does not homogeneously cause FD	3.609989	3.804929	<---->	Feedback
FD does not homogeneously cause REC	5.717322	6.026057		
REC does not homogeneously cause GCF	4.910733	5.175913	<---->	Feedback
GCF does not homogeneously cause REC	5.473964	5.769558		
REC does not homogeneously cause Y	4.040383	4.258563	<---->	Feedback
Y does not homogeneously cause REC	5.985122	6.308319		
FDI does not homogeneously cause FD	1.216791	1.282497	<--	Unidirectional
FD does not homogeneously cause FDI	3.232731	3.407299		
FDI does not homogeneously cause GCF	5.631243	5.93533	-->	Unidirectional
GCF does not homogeneously cause FDI	2.183847	2.301775		
FDI does not homogeneously cause Y	4.158342	4.382893	-->	Unidirectional
Y does not homogeneously cause FDI	1.989373	2.096799		
FD does not homogeneously cause GCF	2.109458	2.223369		None
GCF does not homogeneously cause FD	1.218916	1.284738		
FD does not homogeneously cause Y	4.992561	5.262159	-->	Unidirectional
Y does not homogeneously cause FD	1.756642	1.851501		
GCF does not homogeneously cause Y	5.353879	5.642988	-->	Unidirectional
Y does not homogeneously cause GCF	0.812965	0.856865		

5. Conclusion

The results suggest a strong and statistically significant correlation between the use of renewable energy, the growth of the financial industry, the influx of foreign direct investment, and the generation of gross capital. It seems that foreign direct investment, foreign direct investment, and global capital finance all have a role in promoting the use of renewable energy sources. Both the long-run and short-run evaluations reveal a positive and statistically significant correlation, indicating that these variables may influence the use of renewable energy.

Both the long-term and short-term research demonstrate a clear and statistically significant correlation between foreign direct investment (FDI), foreign direct investment (FD), and global climate financing (GCF). These criteria are crucial for encouraging the use of renewable energy sources. This result, consistent with previous research, highlights the significance of foreign direct investment (FDI), strong financial systems (FD), and capital formation (GCF) in facilitating the shift towards renewable energy sources. A positive coefficient for foreign direct investment (FDI) indicates that FDI has a role in financing the development and enhancement of renewable energy infrastructure and systems. This aligns with the concept that foreign direct investment (FDI) may enhance the use of renewable energy sources via the infusion of funds, facilitation of knowledge transfer, and provision of practical experience [1, 2]. A positive coefficient for financial development indicates that a robust financial infrastructure is crucial for attracting investment for renewable energy projects. This is due to the favorable number of coefficients related to financial development. The positive coefficient of gross capital formation underscores the crucial significance of investments in physical assets and infrastructure in promoting the use of renewable energy sources. This provides further substantiation that the use and acceptance of renewable energy sources escalated in tandem with heightened investments in the infrastructure and technologies pertaining to these sources. The results demonstrate the positive impact of foreign direct investment, foreign direct investment, and global climate finance in promoting the inclusion of clean energy through renewable sources. However, it is crucial to critically analyze the various limitations and concerns associated with these findings. Examine the importance of promoting equitable and sustainable growth in the renewable energy industry, and the possible social and environmental consequences that may arise from significant renewable energy initiatives The research should also include the potential variations in the effects of foreign direct investment (FDI), foreign direct investment (FD), and global climate financing (GCF) across various locations and circumstances. Furthermore, it is essential to establish a robust framework of comprehensive rules and regulations to guarantee that the auxiliary functions of these elements contribute to the expansion of renewable energy consumption in a way that is both sustainable and fair. the results demonstrate a strong and statistically significant correlation between foreign direct investment (FDI), foreign direct investment (FD), global climate finance (GCF), and the utilization of renewable energy. However, further examination is necessary to fully understand the broader implications and factors related to these findings, which will enable us to develop sustainable strategies for integrating renewable energy into our overall energy portfolio.

Policy suggestion

The study findings demonstrate that foreign direct investment (FDI), gross capital formation (GCF), and financial development have a significant and positive impact on the use of renewable energy sources. These findings emphasize the need for well-developed policies and governance systems to ensure sustainable and equitable development in the renewable energy sector. The policy recommendations encompass various measures to enhance the attractiveness of foreign direct investment (FDI) that supports the development of renewable energy infrastructure. This includes implementing comprehensive policy frameworks to encourage the adoption of renewable energy and generate benefits for local communities. Additionally, it involves evaluating the environmental and social impacts of renewable energy projects, focusing on the quality and distribution of domestic capital creation, ensuring financial incentives for renewable energy initiatives, and prioritizing sustainable and inclusive development within the renewable energy industry. The research strongly supports the implementation of long-term strategies that can utilize foreign direct investment (FDI), global capital flows (GCF), and financial development to promote the adoption of renewable energy sources. It also emphasizes the need to address potential environmental and social impacts and promote equitable development.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest is to be disclosed.

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