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Renewable Energy Resilience: The Impact of Economic Policy in South Asia

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Abstract

This study examines the impact of economic policy uncertainty (EPU) on renewable energy adoption in South Asia, a region at the crossroads of rapid economic growth and environmental challenges. Using panel data from 2000 to 2023 and advanced econometric methods, the findings reveal that while EPU can discourage short-term renewable energy investment, it may encourage long-term shifts as firms adapt to uncertainty. Institutional quality, trade openness, and foreign investment emerge as key factors that mitigate the adverse effects of EPU and support renewable energy development. These insights focus on the importance of stable policies and robust institutional frameworks to foster a sustainable energy transition. By leveraging these findings, South Asian policymakers can chart a path toward a resilient, low-carbon future, ensuring that economic development aligns with environmental sustainability and long-term energy security.

Keywords: renewable energy, EPU, South Asia, FDI, institutional quality, financial development.

1. Introduction

South Asia is experiencing a period of remarkable economic growth, with the region's gross domestic product (GDP) increasing by 6.9% over the past decade. This growth is primarily driven by the extensive use of fossil fuels, particularly coal. However, this economic success comes with a significant environmental cost. A recent report by the World Health Organization highlights that air pollution from fossil fuel use is responsible for 21% of premature deaths in South Asia (Lelieveld et al., 2023). This stark contrast between economic prosperity and environmental degradation presents a critical dilemma for policymakers: How can they foster economic growth while ensuring the transition to sustainable, renewable energy sources?

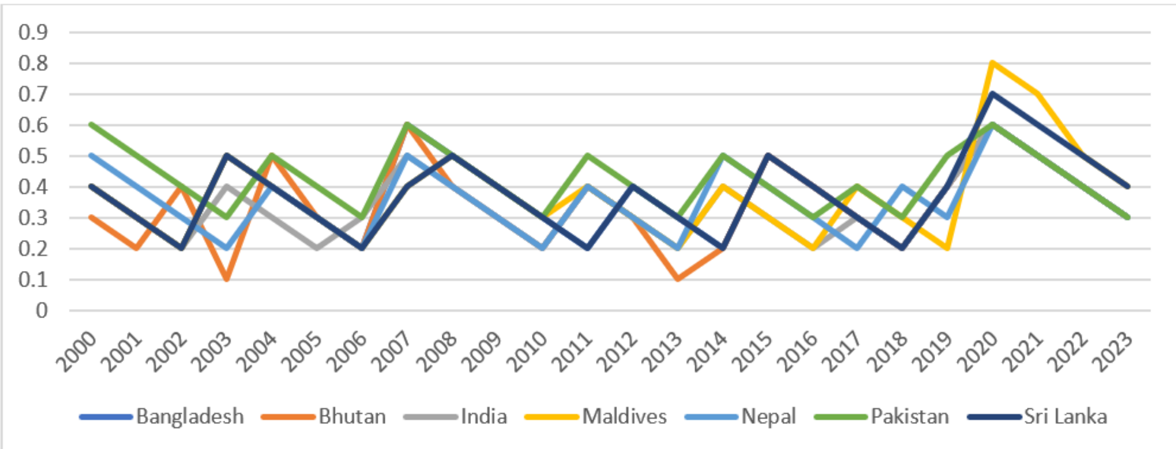
The urgency to combat climate change necessitates a global shift toward REC. South Asia, heavily reliant on fossil fuels, needs a swift transition to cleaner energy sources. However, economic policy uncertainty (EPU) creates a significant barrier. EPU discourages investments in renewable energy projects due to the real options effect, where firms hesitate to invest under unclear policy environments. This research aims to understand how EPU interacts with other factors that can influence the adoption of renewable energy.

The global shift toward renewable energy sources such as solar, wind, and hydropower offers a sustainable alternative to fossil fuels, helping mitigate environmental impact while meeting energy demands (Nair et al., 2021).

While the global transition to renewable energy is critical, it is important to distinguish between "clean" and "renewable" energy. Jaiswal et al. (2022) define clean energy as producing minimal environmental impact, while renewable energy comes from naturally replenished sources like solar, wind, hydropower, and biomass. Nuclear energy, though clean due to low carbon emissions, is not universally renewable due to finite uranium resources and waste concerns. This study focuses on renewable energy sources such as solar, wind, and hydropower, which are sustainable options for South Asia.

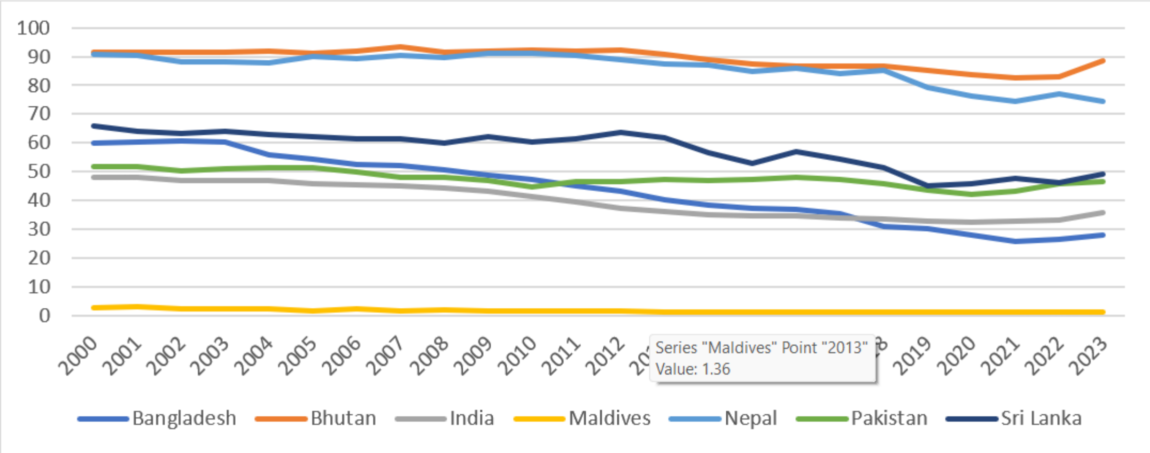
Przychodzen and Przychodzen (2020) noticed that while renewable energy adoption has been studied extensively across various regions, a closer examination of South Asia is needed due to the region's diverse economic structures and varied levels of renewable energy consumption (REC). Bhutan has a significantly higher share of renewable energy in its energy mix (Llamosas & Sovacool, 2021), whereas Pakistan struggles with stagnant REC (Ahmad et al., 2022). Understanding how EPU interacts with these distinct national contexts is vital for crafting effective energy policies in South Asia.

Figure 1. Economic policy uncertainty scenario of South Asian countries



Figures 1 and 2 illustrate the complex relationship between EPU and REC across South Asia. The EPU values in Figure 1 represent the degree of unpredictability in economic policies, with values closer to 1 indicating high uncertainty and values near 0 signifying stable policy environments. Similarly, the REC values in Figure 2 are expressed as percentages, ranging from 0 to 100, where 0 indicates no use of renewable energy, and 100 signifies that the entire energy mix is derived from renewable sources.

Figure 2. Renewable energy consumption pattern of South Asian countries



These clarifications are essential for interpreting the figures and understanding the interplay between EPU and REC in South Asia. While stable economies like Bhutan have a high share of renewable energy, countries such as the Maldives face both high EPU and low REC. India, despite its major investments in renewable energy, shows mixed results, suggesting that EPU may not be the sole factor influencing REC. Countries like Nepal and Sri Lanka, with fluctuating EPU, also exhibit declines in renewable energy use, emphasizing the vulnerability of hydropower to both policy changes and climate variations.

The stagnant REC in Pakistan, as noted by Malik et al. (2020), suggests a need for more stable economic policies to encourage the adoption of renewables. EPU creates a hesitant investment climate, especially given the high upfront costs and long payback periods associated with renewable energy projects (Yun & Yusoff, 2019).

This study aims to explore the interplay between EPU and REC, considering the moderating roles of institutional quality (INSTQ), trade openness (TRADE), foreign direct investment (FDI), and financial development (FD). By examining these factors, the study seeks to provide valuable insights for policymakers, enabling them to design strategies that promote long-term investments in renewable energy infrastructure. Ultimately, these insights could contribute to a cleaner and more sustainable future for South Asia.

While prior studies have explored the relationship between EPU and REC globally, a comprehensive analysis focused on South Asia remains underexplored. Previous research has highlighted the negative impacts of EPU on renewable energy investments, but the specific economic and institutional contexts of South Asian countries have not been sufficiently addressed (Przychodzen & Przychodzen, 2020). The diversity within the region, where countries exhibit varying levels of renewable energy adoption and economic policy stability, warrants a more tailored investigation. The role of other factors, such as FDI, FD, INSTQ, and TRADE, in mitigating the effects of EPU on REC has not been fully explored in the South Asian context.

This study fills these gaps by analyzing the dynamic relationship between EPU and REC in South Asia, incorporating key factors like FDI, FD, INSTQ, and TRADE. By doing so, it offers a detailed understanding of the challenges and opportunities for renewable energy adoption in the region, providing actionable insights that can inform effective policy decisions.

The remainder of this paper is structured as follows: Chapter 2 provides a comprehensive literature review, identifying research gaps and formulating research questions. Chapter 3 outlines the data and methodology employed in the study. Chapter 4 presents and analyzes the empirical findings, relating them to existing research and exploring policy implications. Finally, chapter 5 summarizes the key findings, emphasizing the study’s contributions to the field and suggesting pathways for fostering a more sustainable South Asia.

2. Literature Review

2.1 Effects of Economic Policy Uncertainty on Renewable Energy Consumption

EPU has been a significant area of research, particularly regarding its impact on REC. This section reviews the effects of EPU on REC, focusing on groups of countries and individual countries. Wei et al. (2021) examined the relationship between EPU and REC in South Asia and identified a negative relationship, indicating that higher economic uncertainty leads to lower REC. Canh et al. (2020) extended this analysis globally and confirmed a similar negative association between EPU and REC, suggesting that increased uncertainty hinders REC adoption worldwide.

In contrast, Chen et al. (2024) found a less clear relationship in China, indicating that the effects of EPU may vary depending on national contexts. Furthermore, Khan and Su (2022) investigated the role of monetary policy volatility on REC in the United States and concluded that increased volatility negatively impacts REC. These studies highlight the nuanced relationship between EPU and REC, emphasizing the need for further research to understand country-specific implications.

2.2 Foreign Direct Investment and Renewable Energy Consumption

FDI is another critical factor influencing REC. The role of FDI in fostering renewable energy development has been debated in the literature. Mahbub et al. (2022) and Dai Hung (2024) both found positive associations between FDI and REC in South Asia and globally, respectively. They suggest that FDI can provide the necessary capital and technology to accelerate the adoption of renewable energy. However, Tan and Uprasen (2022) reported a negative relationship between FDI and REC in the Asia-Pacific region. They attributed this to the dominance of fossil fuel-based industries, which can deter investment in renewable energy.

2.3 Financial Development and Renewable Energy Consumption

Financial development plays a crucial role in facilitating REC by providing the necessary financial resources for renewable energy projects. Kremer (2023) emphasized the importance of well-functioning financial markets in overcoming investment barriers. Empirical studies by Mukhtarov et al. (2022) and Acar et al. (2023) further support a positive relationship between FD and REC in South Asia, highlighting that stronger financial systems contribute to increased REC by making financing more accessible.

2.4 Institutional Quality and Renewable Energy Consumption

The quality of institutions is vital for promoting REC. Strong governance and clear, stable policies are essential to foster renewable energy adoption. Mei (2020) and Heldeweg and Saintier (2020) stress the importance of institutional stability in attracting renewable energy investments. Dewi et al. (2023) explored the relationship between INSTQ and REC across different contexts and suggested that countries with stronger institutions are more likely to achieve higher levels of REC.

2.5 Trade Openness and Renewable Energy Consumption

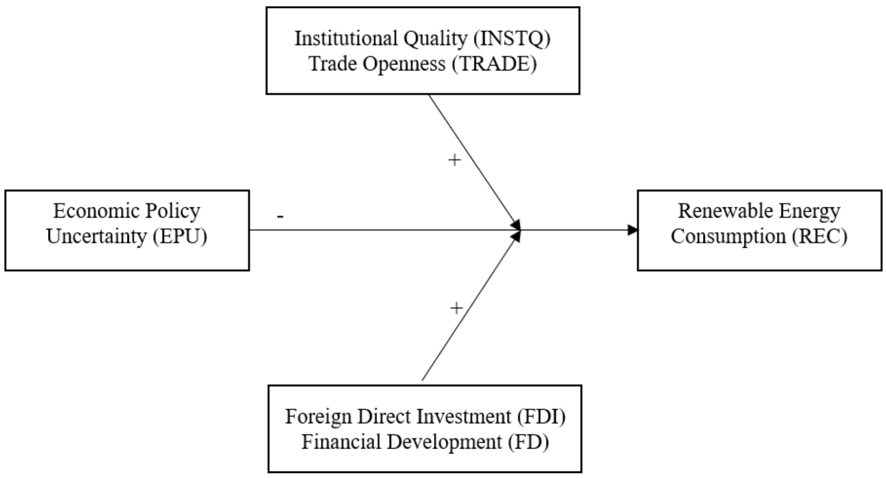
TRADE can also play a significant role in promoting REC by facilitating technology transfer and fostering competition. Wang et al. (2024) and Arshad et al. (2023) argue that open trade policies can promote the adoption of renewable energy technologies, which may increase REC. However, Pata and Caglar (2021) and Bashir (2022) point out the potential downsides of TRADE, such as over-reliance on imports and pollution haven effects, which could limit the development of domestic renewable energy industries.

2.6 Theoretical framework

This study explores how EPU influences REC and the mitigating roles of FDI, FD, INSTQ, and TRADE.

To understand how EPU affects REC, this study draws on real options theory, endogenous growth theory, and institutional theory to examine the relationship between EPU and REC, considering the mitigating roles of FDI, FD, INSTQ, and TRADE (Figure 3). Real options theory suggests that firms view investments as options. EPU creates uncertainty about future returns, making firms hesitant to invest in long-term projects like renewable energy.

Figure 3. The impact of EPU on the RECs and controlling effects of FDI, FD, INSTQ, and TRADE



To explain how other factors can counterbalance EPU, we incorporate endogenous growth theory (Yuan & Zhang, 2024) and institutional theory (Glynn & D'aunno, 2023). Endogenous growth theory suggests that FD, by providing access to capital, can stimulate renewable energy investments. Institutional theory emphasizes the importance of strong institutions in creating a stable environment conducive to long-term investments. Additionally, we consider the role of TRADE in facilitating technology transfer and promoting competition within the renewable energy sector.

By examining these interrelationships, we aim to understand how policymakers can create a favorable environment for renewable energy investments and accelerate the transition to a sustainable future.

2.7 Motivation and proposed hypotheses

Based on the existing literature review, we propose the following hypotheses:

Hypothesis 1: EPU negatively impacts REC.

This aligns with the real options theory, which posits that uncertainty discourages long-term investments with high upfront costs and extended payback periods, such as those characteristic of renewable energy projects.

Hypothesis 2: Counteracting effects of control variables.

We hypothesize that several control variables mitigate the negative influence of EPU on REC. FDI can have a positive impact on REC by introducing capital and technical expertise for renewable energy development, potentially overcoming investor hesitation caused by EPU (Sadiq et al., 2024). A well-developed financial system can ease access to financing for renewable energy projects, thereby mitigating the financial constraints imposed by EPU. Strong institutions with a stable and predictable legal framework can encourage long-term investments, making renewable energy projects with extended payback periods more attractive despite EPU. While TRADE facilitates technology transfer and cost reduction for renewable energy, concerns exist regarding over-reliance on imports and the pollution haven effect (Chowdhury et al., 2021). Therefore, the relationship between TRADE and REC is expected to be positive but requires further investigation.

3. Data and methodology

3.1 Data

To know the impact of EPU, INSTQ, TRADE, FDI, and FD on REC, this study used yearly data from 2000 to 2023 for all South Asian countries, namely Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, and Sri Lanka, except Afghanistan, due to the non-availability of the data. All the data have been collected from the World Bank and the central banks of selected countries. Table 1 summarizes the variables, their units of measure, and corresponding data sources.

Table 1. Summary of variables, units, and data sources

Variable Name	Units of Measure	Data Source
Economic Policy Uncertainty (EPU)	Index or points	Federal Reserve Economic Data (FRED)
Renewable Energy Consumption (REC)	Percentage of total energy consumption	World Bank – Renewable Energy Consumption
Institutional Quality (INSTQ)	Index or scores	World Bank – Worldwide Governance Indicators
Financial Development (FD)	Index or scores	World Bank – Global Financial Development
Foreign Direct Investment (FDI)	US Dollars or Percentage of GDP	World Bank – FDI
Trade Openness (TRADE)	Percentage of GDP	World Bank – WITS

3.2 Methodology

This study systematically investigates the short- and long-run relationships, as well as the causal effects, between the variables of interest. To achieve the stated objectives, the methodology begins with stationarity testing using the Augmented Dickey-Fuller (ADF), Phillips-Perron (PP), and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) tests to identify the integration order of variables. The Autoregressive Distributed Lag (ARDL) bound testing approach is then applied to determine cointegration and estimate both long-run coefficients and short-run dynamics. If cointegration is confirmed, a Vector Error Correction Model (VECM) is employed to capture the speed of adjustment to equilibrium after a shock and estimate short-run elasticities. Finally, the Granger causality test is conducted to analyze the direction of causality between variables, distinguishing between short- and long-run causal effects. This systematic approach ensures a comprehensive understanding of the relationships and causal dynamics, aligning with the study's objective of exploring the impact of economic policy and other factors on REC in South Asia.

3.2.1 Autoregressive Distributed Lag (ARDL) Bounds Testing

In recent years, econometricians have developed several cointegration tests to assess long-run relationships between variables. Popular choices include the Wagner (2023) residual-based test and the maximum likelihood Johansen tests (Gianfreda et al., 2023). Recognizing limitations in earlier models, Xiang et al. (2023) introduced the ARDL model, an OLS-based approach offering greater flexibility. According to Kripfganz and Schneider (2023), the ARDL model can be transformed to derive a dynamic error correction model (ECM).

This study leverages panel data from 7 countries for 24 years. This makes the ARDL model a particularly well-suited choice. It excels at analyzing data with shorter time series, allowing us to assess both long-run relationships through cointegration analysis and capture short-run dynamics simultaneously. Bounds testing within the ARDL framework eliminates the need to predetermine the order of integration for the variables, further streamlining the analysis. The model specification is illustrated below:

$$REC_{it} = \alpha + \beta_0 EPU_{it} + \beta_1 EPU_{it-1} + \cdots + \beta_n EPU_{it-n} + \gamma'^{INSTQ_{it}} + \delta'^{TRADE_{it}} + \varepsilon'^{FDI_{t_t}} + \\ + \theta' FD_t + \delta_{it} + \varepsilon_{it} \quad (1)$$

Where, REC_{it} is the REC in country i at time t, EPU_{it} indicates EPU in country i at time t, EPU_{it-1} to EPU_{it-n} are the lagged values of EPU to capture short-run dynamics, while n is chosen based on model diagnostics, $INSTQ_{it}$, $TRADE_{it}$, FDI_{it}, and FD_{it} are the mitigating variables at time t, and α is the constant term. β, γ, δ, ε, and θ stand for coefficients to be estimated, δ_{it} is the country-specific fixed effects, and ε_{it} is the error term. The generalized form of the ARDL model for the study is as follows:

$$\Delta ln(REC)_t = C_0 + \beta_1 \Delta ln(EPU)_{t-1} + \beta_2 \Delta ln(INSTQ)_{t-1} + \beta_3 \Delta ln(TRADE)_{t-1} + \beta_4 \Delta ln(FDI)_{t-1} + \beta_5 \Delta ln(FD)_{t-1} + \beta_6 \Delta log(REC)_t + \lambda_0 log(REC)_t + \lambda_1 log(EPU)_t + \lambda_2 log(INSTQ)_t + \lambda_3 log(TRADE)_t + \lambda_4 log(FDI)_t + \lambda_5 log(FD)_t + \varepsilon_t \quad (2)$$

Where, Δ represents the difference between a variable at two points in time, ε_t captures any unexplained factors, often referred to as white noise, $(t-1)$ indicates the lagged value of a variable, one period in the past, and λ_0 to λ_5 represent the long-run coefficients, while β_1 to β_6 capture the short-run effects.

3.2.2 Vector Error Correction Model (VECM)

To explore the long-term relationship between REC, EPU, and other relevant factors in South Asian countries, we employ an unrestricted ECM within the ARDL framework. This approach allows us to examine each variable as the dependent variable in turn. The matrix form of this model is given below:

$$\begin{bmatrix} \Delta REC_{ti} \\ \Delta EPU_{ti} \\ \Delta INSTQ_{ti} \\ \Delta TRADE_{ti} \\ \Delta FDI_{ti} \\ \Delta FD_{ti} \end{bmatrix} = \begin{bmatrix} \delta_1 \\ \delta_2 \\ \delta_3 \\ \delta_4 \\ \delta_5 \\ \delta_6 \end{bmatrix} = \sum_s^q \begin{bmatrix} \theta_{11ik}\theta_{12ik}\theta_{13ik}\theta_{14ik}\theta_{15ik}\theta_{16ik} \\ \theta_{21ik}\theta_{22ik}\theta_{23ik}\theta_{24ik}\theta_{25ik}\theta_{26ik} \\ \theta_{31ik}\theta_{32ik}\theta_{33ik}\theta_{34ik}\theta_{35ik}\theta_{36ik} \\ \theta_{41ik}\theta_{42ik}\theta_{43ik}\theta_{44ik}\theta_{45ik}\theta_{46ik} \\ \theta_{51ik}\theta_{52ik}\theta_{53ik}\theta_{54ik}\theta_{55ik}\theta_{56ik} \\ \theta_{61ik}\theta_{62ik}\theta_{63ik}\theta_{64ik}\theta_{65ik}\theta_{66ik} \end{bmatrix} \begin{bmatrix} \Delta REC_{ti-s} \\ \Delta EPU_{ti-s} \\ \Delta INSTQ_{ti-s} \\ \Delta TRADE_{ti-s} \\ \Delta FDI_{ti-s} \\ \Delta FD_{ti-s} \end{bmatrix} + \begin{bmatrix} \gamma_{1it} \\ \gamma_{2it} \\ \gamma_{3it} \\ \gamma_{4it} \\ \gamma_{5it} \\ \gamma_{6it} \end{bmatrix} ECT_{it-1} + \begin{bmatrix} \varepsilon_{1ti} \\ \varepsilon_{2ti} \\ \varepsilon_{3ti} \\ \varepsilon_{4ti} \\ \varepsilon_{5ti} \\ \varepsilon_{6ti} \end{bmatrix}$$

(3)

3.2.3 Granger-Causality Test

To build upon our analysis of long-run and short-run relationships among variables in each South Asian country, we will employ a VECM Granger-causality test to explore the direction of causality between these variables. This test will be applied using the following VECM Granger causality model:

$$\begin{bmatrix} \Delta REC_t \\ \Delta EPU_t \\ \Delta INSTQ_t \\ \Delta TRADE_t \\ \Delta FDI_t \\ \Delta FD_t \end{bmatrix} = \begin{bmatrix} \delta_1 \\ \delta_2 \\ \delta_3 \\ \delta_4 \\ \delta_5 \\ \delta_6 \end{bmatrix} + \begin{bmatrix} \Delta REC_{t-1} \\ \Delta EPU_{t-1} \\ \Delta INSTQ_{t-1} \\ \Delta TRADE_{t-1} \\ \Delta FDI_{t-1} \\ \Delta FD_{t-1} \end{bmatrix} \begin{bmatrix} \theta_{11}\theta_{12}\theta_{13}\theta_{14}\theta_{15}\theta_{16} \\ \theta_{21}\theta_{22}\theta_{23}\theta_{24}\theta_{25}\theta_{26} \\ \theta_{31}\theta_{32}\theta_{33}\theta_{34}\theta_{35}\theta_{36} \\ \theta_{41}\theta_{42}\theta_{43}\theta_{44}\theta_{45}\theta_{46} \\ \theta_{51}\theta_{52}\theta_{53}\theta_{54}\theta_{55}\theta_{56} \\ \theta_{61}\theta_{62}\theta_{63}\theta_{64}\theta_{65}\theta_{66} \end{bmatrix} +$$

$$\sum_{s-1}^{q} \begin{bmatrix} \theta_{11k}\theta_{12k}\theta_{13k}\theta_{14k}\theta_{15k}\theta_{16k} \\ \theta_{21k}\theta_{22k}\theta_{23k}\theta_{24k}\theta_{25k}\theta_{26k} \\ \theta_{31k}\theta_{32k}\theta_{33k}\theta_{34k}\theta_{35k}\theta_{36k} \\ \theta_{41k}\theta_{42k}\theta_{43k}\theta_{44k}\theta_{45k}\theta_{46k} \\ \theta_{51k}\theta_{52k}\theta_{53k}\theta_{54k}\theta_{55k}\theta_{56k} \\ \theta_{61k}\theta_{62k}\theta_{63k}\theta_{64k}\theta_{65k}\theta_{66k} \end{bmatrix} \begin{bmatrix} \Delta REC_{t-s} \\ \Delta EPU_{t-s} \\ \Delta INSTQ_{t-s} \\ \Delta TRADE_{t-s} \\ \Delta FDI_{t-s} \\ \Delta FD_{t-s} \end{bmatrix} + \begin{bmatrix} \gamma_{1t} \\ \gamma_{2t} \\ \gamma_{3t} \\ \gamma_{4t} \\ \gamma_{5t} \\ \gamma_{6t} \end{bmatrix} ECT_{\mathbf{t-1}} + \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \\ \varepsilon_{3t} \\ \varepsilon_{4t} \\ \varepsilon_{5t} \\ \varepsilon_{6t} \end{bmatrix}$$

(4)

Long-run elasticities

Based on the established long-run relationship between economic growth and its determinants, this study takes a further step to estimate the long-run elasticities of these determinants on growth. We achieve this by employing an ARDL (m, n, p, q, s, and v) model, where economic REC serves as the dependent variable.

$$REC_t = \sigma_0 + \sum_{k=1}^{m} \beta_k REC_{t-k} + \sum_{k=0}^{n} \gamma_k EPU_{t-k} + \sum_{k=0}^{p} \delta_k INSTQ_{t-k} + \sum_{k=0}^{s} \pi_k FDI_{t-k} + \sum_{k=0}^{v} p_k FD_{t-k} + \varepsilon_t$$

(5)

Short-run elasticities

Having estimated the long-run elasticities, we now turn our attention to the short-run dynamics by employing an ECM. In this model, REC remains the dependent variable. The short-run elasticities can be obtained by specifying the ECM as follows:

$$\Delta REC_t = \sigma_0 + \sum_{k=1}^{m} \beta_k \Delta REC_{t-k} + \sum_{k=0}^{n} \gamma_k \Delta EPU_{t-k} + \sum_{k=0}^{p} \delta_k \Delta INSTQ_{t-k} + \sum_{k=0}^{s} \pi_k \Delta FDI_{t-k} + \sum_{k=0}^{v} p_k \Delta FD_{t-k} + \varphi ECT_{t-1+}\omega_t$$

(6)

4. Findings and Discussion

As Table 2 exhibits, all variables are either integrated at level I(0) or first difference I(1), and no variable is co-integrated at second difference I(2). Thus, we can apply the newly developed cointegration model, widely known as ARDL bound testing (Xiang et al., 2023).

Table 2. Unit root test

	REC	EPU	INSTQ	TRADE	FDI	FD	ΔREC	ΔEPU	ΔINSTQ	ΔTRADE	ΔFDI	ΔFD
						Bangladesh						
ADF	-3.58**	-1.50	-3.25*	-0.56*	-0.85***	-2.89	-4.96**	-4.81**	-3.54**	-3.99*	-3.99***	-4.14
PP	-4.36**	-1.25**	-3.65**	-0.58**	0.08*	-2.42**	-3.25*	-4.25**	-3.21*	-5.86*	-3.69**	-4.58**
KPSS	0.61**	0.82	0.65**	0.81*	0.66**	0.81*	-4.63**	3.95**	2.95**	4.28**	2.69**	0.27*
						Bhutan						
ADF	-3.54**	-1.46**	-3.21	-0.52	-0.81**	-2.85**	-4.74	-2.66**	-4.41**	-1.72**	-2.01*	-4.05**
PP	-4.32**	-1.21	-3.61**	-0.54**	0.12*	-2.38*	-5.52	-2.41**	-4.81*	-1.74***	-1.08**	-3.58*
KPSS	0.65**	0.86**	0.69**	0.85**	0.70**	0.85*	5.87*	2.96*	0.51***	0.35*	0.69**	3.15*
						India						
ADF	-4.50**	-2.42	-4.17*	-1.48*	-1.77*	-3.81**	-1.91	0.17**	-1.58*	-1.11***	-0.82***	-1.22***
PP	-5.28**	-2.17	-4.57	-1.50	-0.84**	-3.34*	-2.69	-0.42**	-1.98**	-1.09*	-1.75*	-0.75*
KPSS	-0.31**	-0.10**	-0.27**	-0.11**	-0.26*	-0.11*	2.28	0.58*	-1.28**	2.48**	2.33**	-0.87**
						Maldives						
ADF	-3.72**	-1.64**	-3.39**	-0.70**	-0.99*	-3.03**	-2.14	-0.06**	-1.81	0.88**	0.59**	-1.45***
PP	-4.50**	-1.39	-3.79	-0.72	-0.06**	-2.56***	-2.92	-0.19**	-2.21**	0.86*	1.52	-0.98*
KPSS	0.47**	0.68**	0.51**	0.67**	0.52*	0.67**	2.05	9.25*	2.09***	2.54*	2.10***	2.25**
						Nepal						
ADF	-3.54**	-1.46	-3.21**	-0.52**	-0.81**	-2.85*	-3.19	-1.11**	-2.86*	-0.17***	-0.46**	-2.50***
PP	-4.32**	-1.21**	-3.61*	-0.54*	0.12**	-2.38**	-3.97	-0.86**	-3.26**	-0.19**	0.47***	-2.03*
KPSS	0.65**	0.86**	0.69**	0.85**	0.70**	0.85*	1.00	1.21**	1.04**	1.20***	1.05*	1.20***

						Pakistan						
ADF	-4.25**	-2.17**	-3.92*	-1.23**	-1.52	-3.56*	-3.54	-1.46**	-3.21*	-0.52***	-0.81***	-2.85*
PP	-5.03**	-1.92	-4.32*	-1.25	-0.59	-3.09	-4.32	-1.21***	-3.61**	-0.54*	0.12**	-2.38***
KPSS	-0.06**	0.15**	-0.02**	0.14*	-0.01**	0.14**	0.65	0.86**	0.56*	0.78**	0.70*	0.54*
						Sri Lanka						
ADF	-3.42**	-1.34*	-3.09	-0.40*	-0.69*	-2.73*	-3.27	-1.19**	-2.94***	-0.25***	-0.54***	-2.58*
PP	-4.20**	-1.09**	-3.49	-0.42**	0.24	-2.26*	-4.05	-0.94**	-3.34*	-0.27**	0.39**	-2.11**
KPSS	0.77**	0.98**	0.81	0.97*	0.82	0.97*	0.92	0.81**	0.96**	0.82*	0.43**	1.12*

Note: ADF = Augmented Dickey–Fuller, PP = Phillips Perron, and KPSS = Kwiatkowski, Phillips, Schmidt, and Shin. ***, **, and * indicate significance levels of 10%, 5%, and 1%, respectively.

Having verified stationarity through tests, ensuring no variables are integrated at I(2), we proceed to analyze the long-term relationship between REC and EPU in selected South Asian countries. We employ the ARDL bounds testing approach developed by Xiang et al. (2023). This method tests the null hypothesis of no cointegration ($H_0 : \theta_1 = \theta_2 = \theta_3 = \theta_4 = \theta_5 = 0$) against the alternative of cointegration ($H_0 : \theta_1 \neq \theta_2 \neq \theta_3 \neq \theta_4 \neq \theta_5 \neq 0$).

Bound testing involves comparing an F-statistic with critical values from Bayer et al. (2023). Table 3 shows the estimated F-statistics. When REC is the dependent variable, all F-statistics exceed the upper bound value (4.68) at the 1% significance level, indicating cointegration.

Table 3. ARDL bound testing

	Bangladesh		Bhutan		India		Maldives		Nepal		Pakistan		Sri Lanka	
	F-stat	Result	F-stat	Result	F-stat	Result	F-stat	Result	F-stat	Result	F-stat	Result	F-stat	Result
REC	19.59	Ǭ	6.61	√	11.25	√	12.11	√	10.58	√	6.42	√	8.13	√
EPU	6.84	√	5.42	Ǭ	6.45	√	6.47	√	7.19	√	5.51	Ǭ	0.72	Ǭ
INSTQ	4.65	√	5.36	Ǭ	7.12	√	7.56	√	5.68	Ǭ	6.15	√	5.32	Ǭ
TRADE	4.71	Ǭ	2.69	Ǭ	6.04	Ǭ	6.98	Ǭ	0.41	Ǭ	1.21	Ǭ	2.99	Ǭ
FDI	1.28	Ǭ	2.84	Ǭ	2.16	Ǭ	2.81	Ǭ	1.69	Ǭ	3.68	Ǭ	1.78	Ǭ
FD	4.71	Ǭ	0.62	Ǭ	1.25	Ǭ	1.28	Ǭ	0.83	Ǭ	1.34	Ǭ	1.25	Ǭ
							1%		5%		10%			
						K	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)		
Critical value: Pearson et al., (2001)						5	3.41	4.68	2.62	3.79	2.26	3.35		
Bayer et al., (2023)						5	4.25	6.04	3.03	4.44	2.5	3.76		

Note: √ = "Cointegration", Ǭ = "no integration", and K is the number of regressors.

For other variables as the dependent variable, the results are mixed. Some F-statistics surpass the upper bound, while others fall below the lower bound. This suggests rejection of the null hypothesis, indicating no cointegration for South Asian countries and implying cointegration between REC and its determinants.

The lag length of the ARDL model is estimated using the Akaike Information Criterion. Using time series data for the study, Xiang et al. (2023) proposed that the maximum lag length is 2. The estimated long-run model coefficients are reported in Table 4, and the coefficients of the long-run model are theoretically expected show statistical significance. So, our estimation advocates that EPU, INSTQ, TRADE, FDI, and FD positively influence the renewable economic growth of South Asian countries for the data period. The table analyzes how various factors influence a country's long-term REC. The coefficients show how much REC is expected to rise for a one-unit increase in each factor.

Table 4. Long-run coefficients – Dependent variable: REC

	Bangladesh	Bhutan	India	Maldives	Nepal	Pakistan	Sri Lanka
EPU	1.15**	0.87**	0.55*	0.81**	0.22**	1.55**	0.63*
INSTQ	0.87**	0.93**	0.29**	0.17**	0.12**	0.88*	0.37**
TRADE	1.09*	0.33**	2.99**	0.89*	1.22**	1.96**	3.96*
FDI	0.33**	2.36*	1.56*	0.09*	0.78*	2.61**	2.54**
FD	0.96*	1.13*	0.65**	0.77**	0.44**	-0.37*	1.65*
Constant	-4.38**	-5.32**	-8.91*	3.81**	-6.51**	-8.99**	-4.65**

Note: EPU = economic policy uncertainty, INSTQ = institutional quality, TRADE = trade openness, FDI = foreign direct investment, and FD = financial development. ** and * indicate significance levels of 5% and 1%, respectively.

A positive coefficient for energy policy uncertainty, like Bangladesh's (1.15), suggests that unclear energy policies push countries toward renewable energy sources as a safety net. Similarly, strong institutions with better policies, as seen by Bhutan's coefficient (0.93), are linked to higher REC. The impact of TRADE varies: A high coefficient for the Maldives (2.99) suggests that easier access to renewable technologies through trade boosts REC significantly. FDI in the sector, like Pakistan's positive coefficient (2.61), is associated with increased REC in the long run due to the influx of capital and expertise. Finally, the relationship between FD and REC is mixed. A positive coefficient for Sri Lanka (1.65) indicates a more developed financial sector facilitating investment in renewable energy projects, whereas a negative coefficient for Pakistan (-0.37) might reflect a preference for traditional energy sources in that context.

Table 5 presents the estimated coefficients for the short-run impact of various factors on REC in South Asian countries. The Error Correction Term (ECT) exhibits negative and statistically significant coefficients across all countries. This indicates that past deviations from equilibrium REC levels are corrected in the current period, with stronger negative coefficients (closer to -2) suggesting faster adjustments.

Table 5. Short-run coefficients under error correction – Dependent variable: REC

	Bangladesh	Bhutan	India	Maldives	Nepal	Pakistan	Sri Lanka
Section A: Short-run coefficient							
ECT (-1)	-1.52**	-1.38**	-1.17**	-1.21**	-1.18**	-1.21**	-1.82*
EPU	1.72**	1.88**	0.69**	-0.86**	0.54*	1.52**	2.42**
INSTQ	1.09**	1.81**	0.37*	0.24**	0.31*	0.45*	1.36**
TRADE	1.64*	2.89*	3.55	0.91**	2.11**	1.91*	2.80*
FDI	1.56**	1.96**	0.34**	0.12	0.91**	2.04**	2.22*
FD	1.64*	3.99**	4.98*	1.02*	-0.58	-0.55*	-1.32**
Section B: Residual diagnosis							
R^2	0.97	0.81	0.94	0.81	0.88	0.78	0.96
δ	0.23	0.11	0.20	0.45	0.47	0.22	0.19
$F^2_{\text{statistics}}$	15.52	6.49	2.41	8.61	1.41	0.78	0.81
$X^2_{\text{Autocorrelation}}$	2.32 (0.20)	3.32 (0.63)	1.43 (0.78)	2.30 (0.19)	1.57 (0.31)	1.14 (0.29)	1.55 (0.39)
$X^2_{\text{Heteroskedasticity}}$	1.92 (0.25)	0.97 (0.86)	0.85 (0.92)	4.92 (0.52)	0.72 (0.63)	1.47 (0.29)	1.67 (0.18)
$X^2_{\text{Normality}}$	0.39 (0.85)	1.72 (0.35)	11.57 (0.54)	0.82 (0.79)	2.19 (0.55)	5.22 (0.33)	4.25 (0.63)
X^2_{RESET}	1.76 (0.23)	6.24 (0.18)	1.77 (0.21)	0.19 (0.87)	0.85 (0.55)	5.33 (0.41)	2.54 (0.28)

Stability test							
CUSUM @5%	Figure 4	Figure 6	Figure 8	Figure 10	Figure 12	Figure 14	Figure 16
CUSUMQ @5%	Figure 5	Figure 7	Figure 9	Figure 11	Figure 13	Figure 15	Figure 17

The effect of EPU is mixed. A positive and significant coefficient is observed in Bangladesh, Bhutan, India, Pakistan, and Sri Lanka. This suggests that short-term policy uncertainty might incentivize these countries to invest in renewable energy as a potential hedge against future risks. However, the coefficient is negative and significant in the Maldives and Nepal, indicating that policy uncertainty discourages renewable energy adoption in these countries.

INSTQ generally has a positive and statistically significant impact on REC, except for India, where the effect is marginally significant. This implies that strong institutions promote REC in most South Asian countries.

The impact of TRADE is also predominantly positive and significant, except for India, where the coefficient is insignificant. This suggests that greater trade integration encourages renewable energy use in most South Asian countries, potentially due to access to advanced renewable energy technologies or trade agreements promoting clean energy.

FDI has a positive and significant impact on REC in all countries except the Maldives, where the effect is insignificant. This implies that foreign investment plays a significant role in boosting REC across South Asia.

The relationship between FD and REC is more complex. A positive and significant effect is observed in Bangladesh, Bhutan, India, and Sri Lanka. However, the coefficient is negative and significant in Nepal and Sri Lanka, and insignificant in the Maldives. This suggests a potential interaction effect, where the impact of FD on REC might depend on how financial resources are directed within each country.

The residual analysis section in Table 5B strongly supports the validity of the model. The model shows high R-squared values ranging from 0.78 to 0.97, indicating it effectively explains a significant portion of the variation in REC. All F-statistics are statistically significant, confirming the importance of the model. Tests for autocorrelation, heteroskedasticity, and misspecification reveal no major concerns in most countries. While non-normality of residuals could be a potential issue in some cases (India, Nepal, Pakistan), the impact might be negligible depending on the sample size.

To ensure stability, we employed the cumulative sum (CUSUM) and cumulative sum of squares (CUSUMQ) tests, as proposed and validated by Wang (2023) in his empirical work. Figures 4–17 demonstrate the robustness of our model by confirming that the proposed model for each country is sufficiently stable for predicting the impact of its determinants on growth.

Figure 4. Plot of cumulative sum of recursive residuals (Bangladesh)

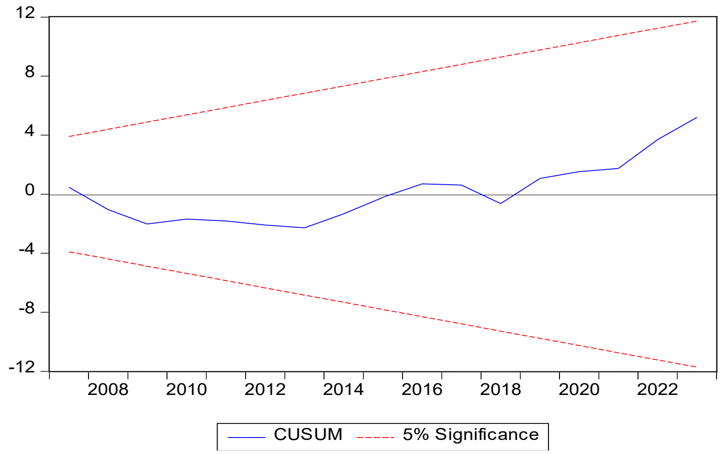


Figure 5. Plot of cumulative sum of squares of recursive residuals (Bangladesh)

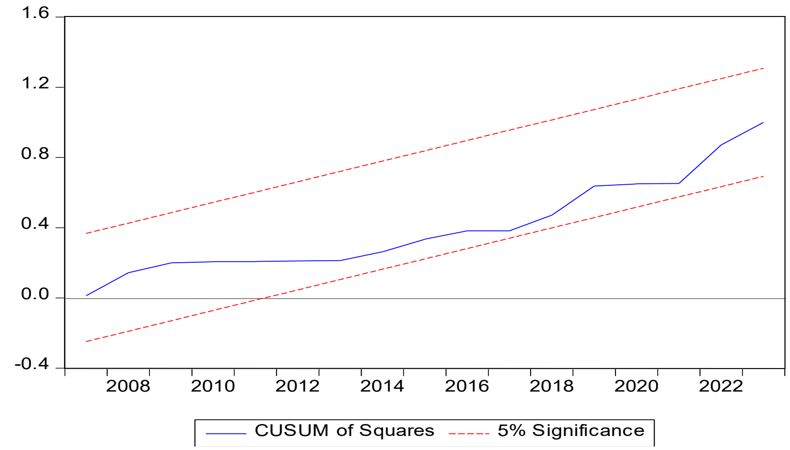


Figure 6. Plot of cumulative sum of recursive residuals (Bhutan)

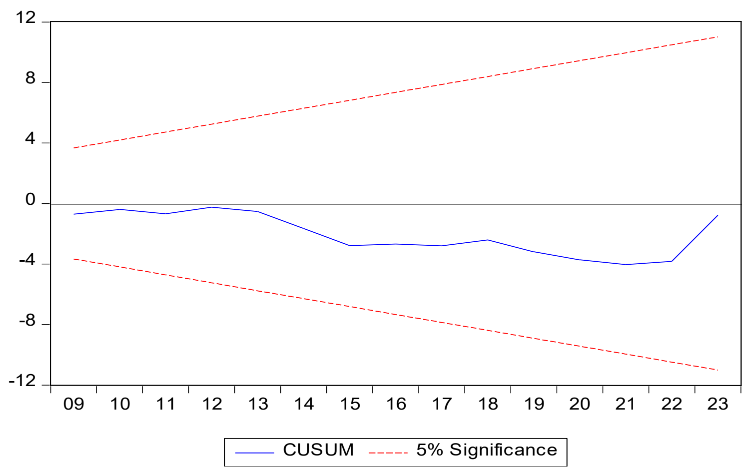


Figure 7. Plot of cumulative sum of squares of recursive residuals (Bhutan)

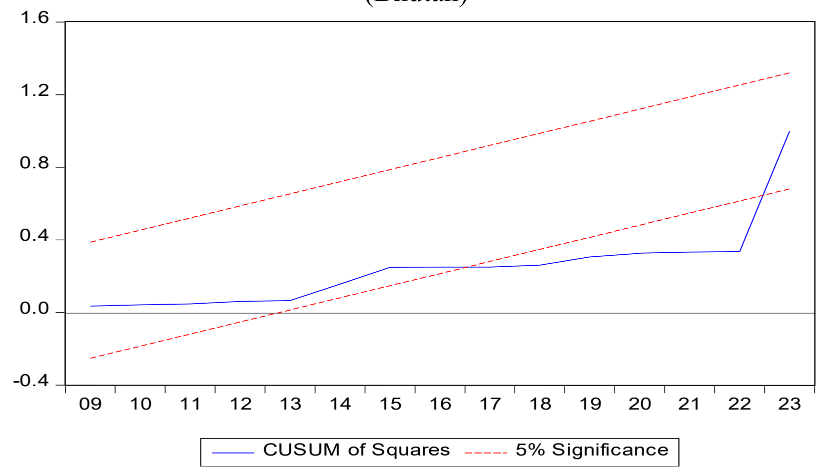


Figure 8. Plot of cumulative sum of recursive residuals (India)

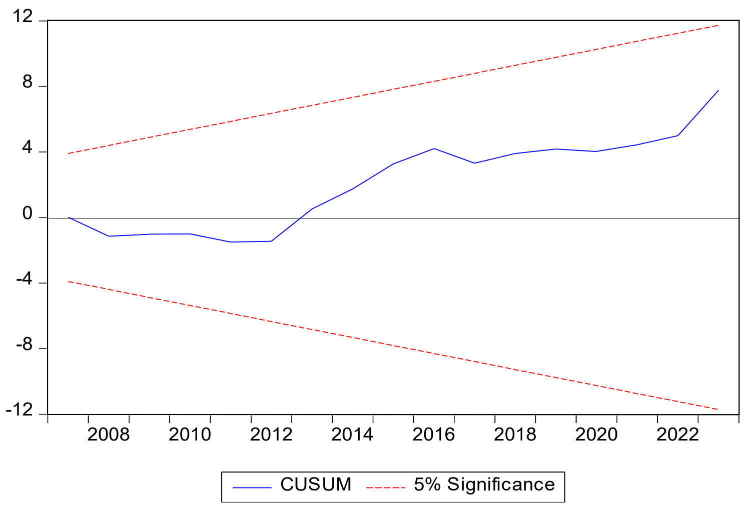


Figure 9. Plot of cumulative sum of squares of recursive residuals (India)

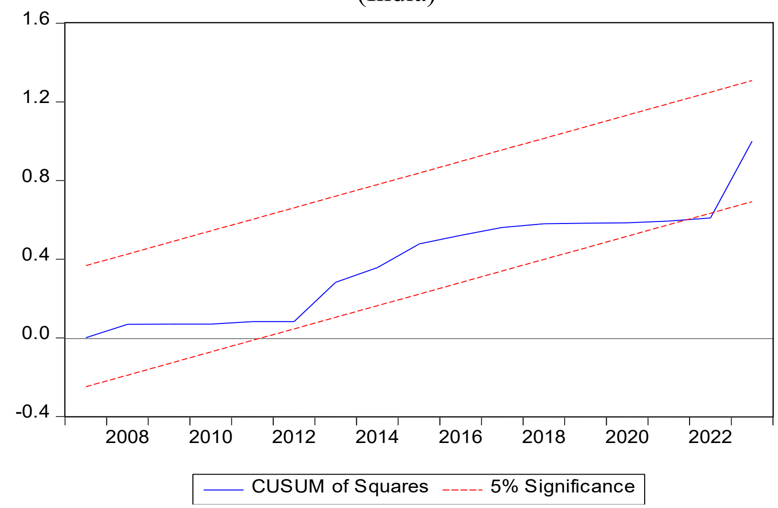


Figure 10. Plot of cumulative sum of recursive residuals (Maldives)

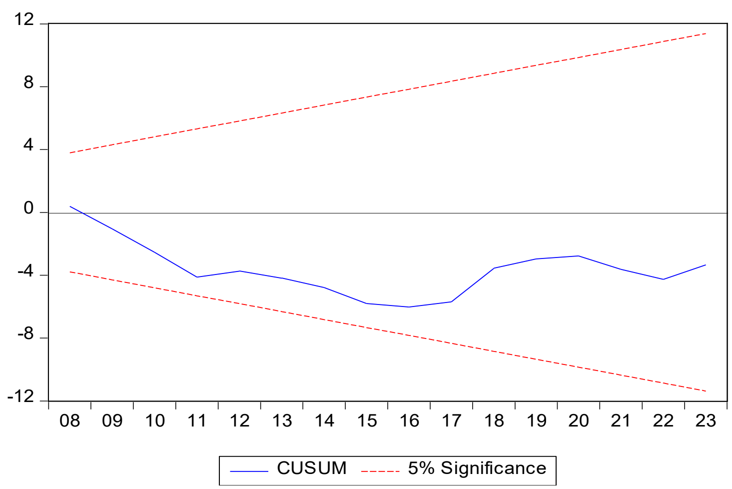


Figure 11. Plot of cumulative sum of squares of recursive residuals (Maldives)

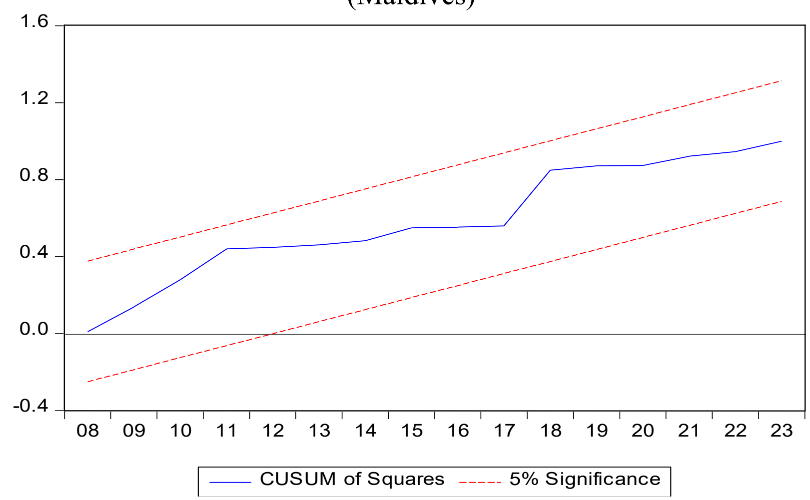


Figure 12. Plot of cumulative sum of recursive residuals (Nepal)

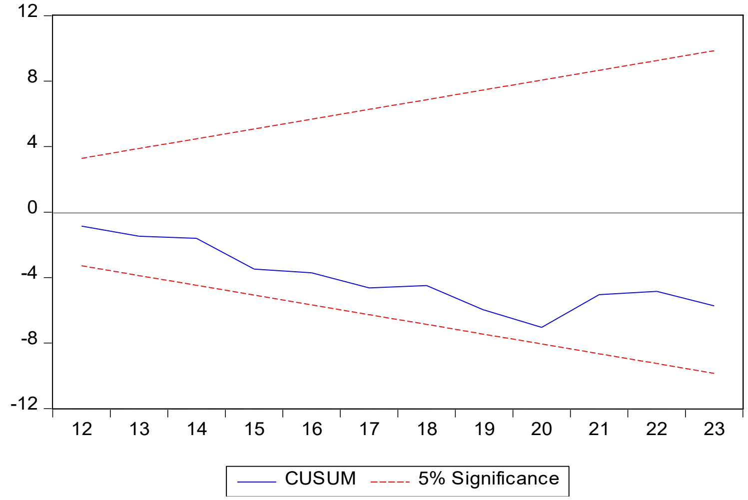


Figure 13. Plot of cumulative sum of squares of recursive residuals (Nepal)

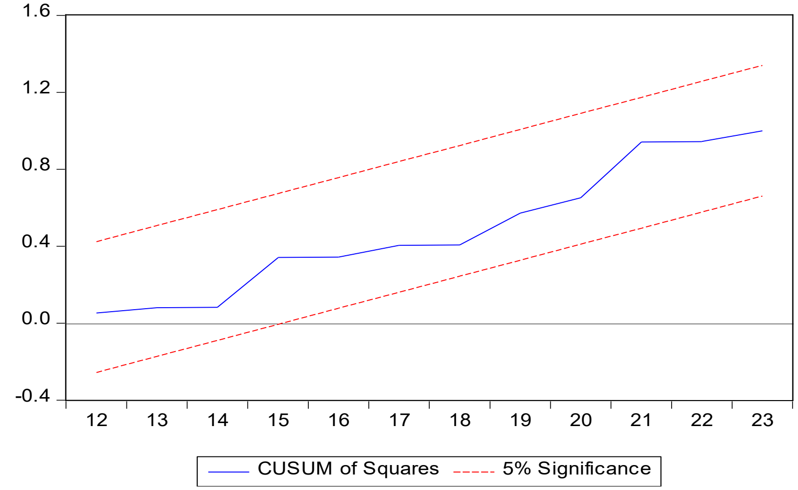


Figure 14. Plot of cumulative sum of recursive residuals (Pakistan)

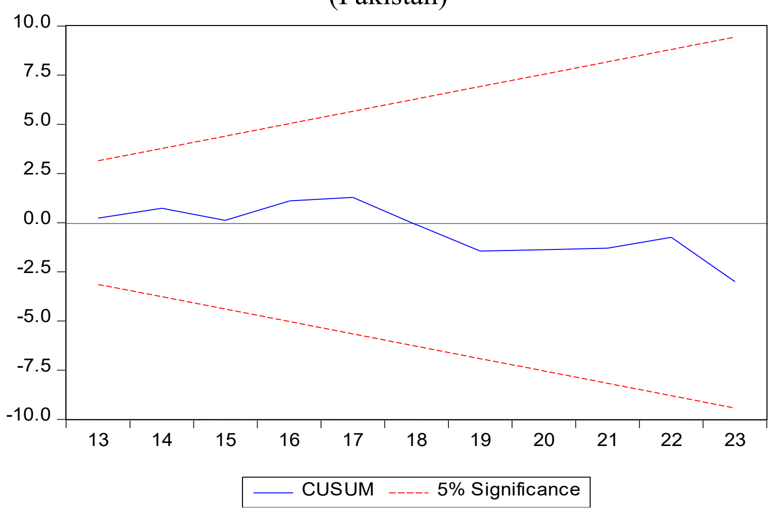


Figure 15. Plot of cumulative sum of squares of recursive residuals (Pakistan)

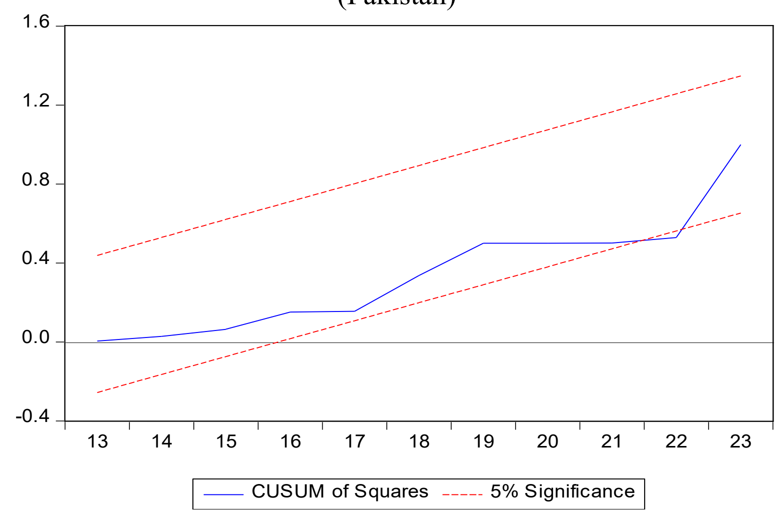


Figure 16. Plot of cumulative sum of recursive residuals (Sri Lanka)

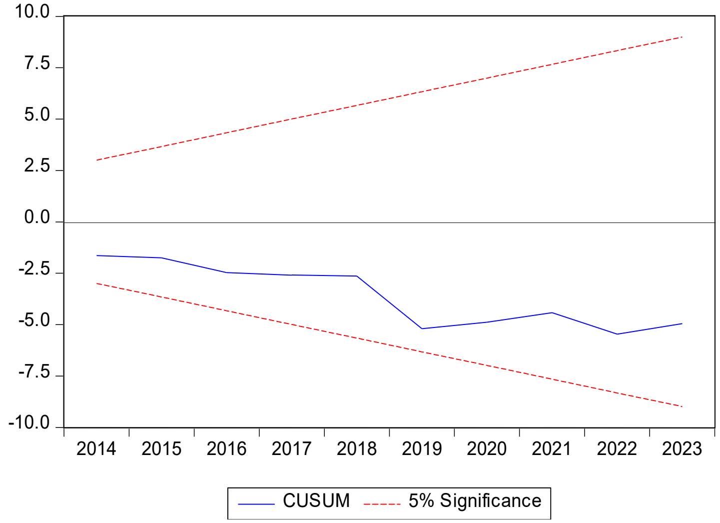


Figure 17. Plot of cumulative sum of squares of recursive residuals (Sri Lanka)

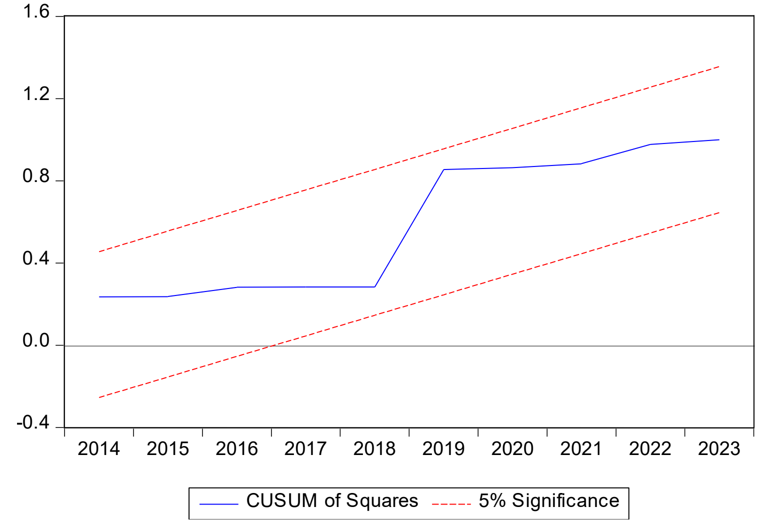


Table 6 exhibits that, in Bangladesh, the bidirectional causality between REC and EPU suggests mutual influences between renewable energy and policy uncertainty, likely due to policy changes affecting renewable energy deployment and vice versa. The unidirectional causalities from REC to TRADE and FD, and from FDI to REC, indicate that the renewable energy sector can drive trade and FD, while foreign investment promotes renewable energy growth.

Table 6. VECM Granger causality test

	ΔREC_t	ΔEPU_t	$\Delta INSTQ_t$	$\Delta TRADE_t$	ΔFDI_t	ΔFD_t
			Bangladesh			
			Short-run causality			
REC_{t-1}	-	10.71**	0.35**	0.26*	6.25*	8.92

EPU $_{t-1}$	0.36**	-	0.90	0.14	4.97**	5.69
INSTQ $_{t-1}$	1.21*	2.27**	-	0.98**	8.84	1.74**
TRADE $_{t-1}$	0.15	6.24*	0.39	-	8.40**	0.80
FDI $_{t-1}$	0.10**	2.84*	1.82**	0.35**	-	0.38**
FD $_{t-1}$	0.06**	1.86	0.41	0.18	5.85**	-
			Long-run causality			
ECT$_{-1}$	-0.75**	-0.34**	-0.05*	-0.71**	-0.52	-0.17**
	Long-run causality	Long-run causality	Long-run causality	Long-run causality		Long-run causality
			Bhutan			
			Short-run causality			
REC$_{t-1}$	-	12.53**	16.97**	0.07	1.25**	4.52**
EPU $_{t-1}$	5.92**	-	11.81**	0.81**	1.49	1.29
INSTQ $_{t-1}$	0.88**	2.02**	-	1.72	1.16**	0.94
TRADE $_{t-1}$	2.58	2.85*	39.13**	-	2.77**	6.55*
FDI $_{t-1}$	0.55**	4.59**	15.51	0.04*	-	4.80*
FD $_{t-1}$	0.49	3.92	2.76	0.61**	0.23**	
			Long-run causality			
ECT$_{-1}$	-0.38**	-0.06**	-0.94**	-0.04	-0.80	0.18
	Long-run causality	Long-run causality	Long-run causality			
			India			
			Short-run causality			
REC$_{t-1}$	-	6.26**	0.31**	4.23	0.67	0.45**
EPU $_{t-1}$	0.86**	-	0.02**	3.20	4.19**	0.95

INSTQ $_{t-1}$	3.35**	1.19	-	0.83**	0.47	0.51**
TRADE $_{t-1}$	0.29**	0.59**	0.64	-	2.62**	1.16
FDI $_{t-1}$	1.23**	2.42	1.29*	2.90	-	0.48*
FD $_{t-1}$	0.85	4.57**	0.83*	2.01	0.78**	-
			Long-run causality			
ECT$_{-1}$	-1.52**	-0.21**	-0.58**	0.13	0.10**	-0.37**
	Long-run causality	Long-run causality	Long-run causality		Long-run causality	Long-run causality
			Maldives			
			Short-run causality			
REC$_{t-1}$	-	6.51**	0.31**	4.21	0.65	0.45**
EPU $_{t-1}$	0.47**	-	0.02**	2.20	4.80**	0.94
INSTQ $_{t-1}$	3.12**	1.80	-	0.27**	0.64	0.51**
TRADE $_{t-1}$	0.81**	0.84**	0.35	-	2.14**	1.16
FDI $_{t-1}$	1.21**	2.13	1.81*	2.08	-	0.48*
FD $_{t-1}$	0.47	4.46**	0.27*	2.07	0.66**	
			Long-run causality			
ECT$_{-1}$	-1.14**	-0.09**	-0.47**	0.11	-0.15**	-0.14**
	Long-run causality	Long-run causality	Long-run causality		Long-run causality	Long-run causality
			Nepal			
			Short-run causality			
REC$_{t-1}$	-	8.97**	0.23**	16.25	1.21*	8.74
EPU $_{t-1}$	7.68**	-	1.71	0.13**	0.20	4.92
INSTQ $_{t-1}$	1.87**	2.47**	-	0.31	0.29**	0.14

$TRADE_{t-1}$	3.82	0.52*	0.72**	-	1.71	0.16
FDI_{t-1}	1.51	0.63**	1.25	0.61	-	0.58*
FD_{t-1}	1.35*	0.61**	1.91	0.92	1.10**	-
			Long-run causality			
	-1.27**	-0.90**	-0.24**	-0.41*	-0.20	-0.12*
	Long-run causality	Long-run causality	Long-run causality	Long-run causality		Long-run causality
			Pakistan			
			Short-run causality			
REC_{t-1}	-	0.79**	1.81*	0.91**	0.18	0.42
EPU_{t-1}	2.45**	-	1.29	0.19**	1.61	1.97**
$INSTQ_{t-1}$	0.28**	8.92*	-	0.71	1.69**	0.08*
$TRADE_{t-1}$	0.92	0.59**	0.14**	-	0.27**	1.63**
FDI_{t-1}	0.63	0.73*	3.81	0.92	-	4.67
FD_{t-1}	0.07*	0.81	0.78*	0.51**	4.87	-
			Long-run causality			
ECT_{-1}	-0.36**	0.71*	-1.10**	-0.21**	0.04**	0.13
	Long-run causality	Long-run causality	Long-run causality	Long-run causality	Long-run causality	
			Sri Lanka			
			Short-run causality			
REC_{t-1}	-	0.49**	1.32*	7.39	1.91	1.38**
EPU_{t-1}	1.60**	-	1.40	1.29	3.92*	5.13
$INSTQ_{t-1}$	2.40**	1.25	-	12.34**	1.21	3.26*
$TRADE_{t-1}$	0.64*	4.63*	0.61	-	1.92**	0.26*

FDI_{t-1}	0.81**	0.36	1.74	2.67*	-	2.31**
FD_{t-1}	1.54**	0.48	0.14**	0.67	1.40**	-
			Long-run causality			
ECT_{-1}	-0.28**	-0.50**	-0.54**	-0.19**	-0.71	-0.32*
	Long-run causality	Long-run causality	Long-run causality	Long-run causality		Long-run causality

Bhutan's results show a bidirectional relationship between REC, EPU, and FD, highlighting the intertwined nature of these factors. The unidirectional causality from INSTQ to REC, TRADE, and FDI emphasizes the importance of INSTQ in shaping these domains.

India's findings also display bidirectional causalities between REC, EPU, and INSTQ, suggesting mutual impacts among renewable energy, policy uncertainty, and INSTQ. Unidirectional causalities from REC to TRADE and FDI, and from EPU to TRADE, FDI, and FD, indicate the broader implications of renewable energy and EPU.

The patterns observed in the Maldives, Nepal, Pakistan, and Sri Lanka are similar, with bidirectional and unidirectional causal linkages reflecting the complex and country-specific dynamics between the studied variables.

The Granger causality analysis in Table 7 provides insights into the dynamic relationships between the variables. In Bangladesh, the bidirectional causalities between REC, EPU, and INSTQ suggest that changes in REC and EPU, as well as the quality of institutions, mutually influence each other. This could be due to policy changes affecting renewable energy investment and vice versa, while the institutional environment also plays a crucial role in these interactions. Bangladesh exhibits unidirectional causalities, where REC drives TRADE and FD, while FDI promotes REC.

This indicates that the expansion of the renewable energy sector may lead to increased trade activities and financial sector development, while FDI inflows contribute to the growth of the renewable energy industry.

Table 7. Brief scenario of short-run Granger-causality

Causal relationships as per model	Bangladesh	Bhutan	India	Maldives	Nepal	Pakistan	Sri Lanka
REC vs. EPU	REC←→EPU	REC←→EPU	REC←→EPU	REC←→EPU	REC←→EPU	REC←→EPU	REC←→EPU
REC vs. INSTQ	REC←→INSTQ	REC←INSTQ	REC←→INSTQ	REC←→INSTQ	REC←→INSTQ	REC←→INSTQ	REC←→INSTQ
REC vs. TRADE	REC→TRADE	NA	REC→TRADE	REC→TRADE	NA	NA	REC←TRADE
REC vs. FDI	REC←FDI	REC←→FDI	REC→FDI	REC→FDI	NA	REC→FDI	REC←FDI
REC vs. FD	REC→FD	REC←→FD	REC←FD	REC←FD	REC←FD	REC←FD	REC←→FD
EPU vs. INSTQ	EPU→INSTQ	EPU←→INSTQ	EPU←INSTQ	EPU←INSTQ	EPU←INSTQ	EPU←INSTQ	NA
EPU vs. TRADE	EPU←→TRADE	EPU←→TRADE	EPU←TRADE	EPU←TRADE	EPU←→TRADE	EPU←TRADE	EPU←TRADE
EPU vs. FDI	EPU←→FDI	EPU←FDI	EPU←FDI	EPU←FDI	EPU←FDI	EPU←FDI	EPU→FDI
EPU vs. FD	NA	NA	EPU←FD	EPU←FD	EPU←FD	NA	NA
INSTQ vs. TRADE	INSTQ→TRADE	INSTQ←TRADE	INSTQ←TRADE	INSTQ←TRADE	INSTQ←TRADE	INSTQ←TRADE	INSTQ→TRADE
INSTQ vs. FDI	INSTQ→FDI	INSTQ→FDI	INSTQ←FDI	INSTQ←FDI	INSTQ→FDI	INSTQ→FDI	NA
INSTQ vs. FD	INSTQ→FD	NA	INSTQ←FD	INSTQ←FD	NA	INSTQ←FD	INSTQ←FD

TRADE vs. FDI	TRADE←FDI	TRADE←→FDI	TRADE→FDI	TRADE→FDI	NA	NA	TRADE←FDI
TRADE vs. FD	TRADE→FD	TRADE←FD	NA	NA	NA	NA	TRADE→FD
FDI vs. FD	FDI→FD	FDI←→FD	FDI←FD	FDI←FD	FDI→FD	FDI←→FD	FDI←→FD

Note: → denotes unidirectional causality, ←→ indicates bidirectional causality, and NA means no causality between variables.

The causal relationships in Bhutan exhibit a similar pattern, with bidirectional links between REC, EPU, and FD. This implies a complex interplay between renewable energy, policy uncertainty, and FD. Notably, INSTQ appears to Granger-cause REC, TRADE, and FDI in Bhutan, highlighting the important role of INSTQ in shaping these domains.

In the case of India, the bidirectional relationships between REC, EPU, and INSTQ suggest mutual influences among renewable energy, policy uncertainty, and INSTQ. India also showcases unidirectional causalities, where REC drives TRADE and FDI, while FD is influenced by REC. Conversely, EPU is affected by TRADE, FDI, and FD, indicating that policy uncertainty is related to external and financial factors in the Indian context.

The Maldives exhibits a comparable pattern, with bidirectional causalities between REC, EPU, and INSTQ. REC is found to Granger-cause TRADE and FDI, while FD is influenced by both REC and EPU. Interestingly, INSTQ is affected by EPU, TRADE, and FDI, highlighting the importance of INSTQ in the Maldivian economy.

In Nepal, the bidirectional relationships between REC, EPU, and INSTQ point to the complex interactions among these variables. While REC is influenced by FDI, FD is Granger-caused by REC and EPU. INSTQ affects TRADE and FDI, emphasizing the role of INSTQ in Nepal's external sector and FD.

The Granger causality results for Pakistan exhibit bidirectional relationships between REC, EPU, INSTQ, and FD, indicating mutual influences among these variables. REC is affected by TRADE, while FDI promotes REC. On the other hand, EPU is influenced by TRADE and FDI, suggesting that policy uncertainty is related to external factors in Pakistan.

Sri Lanka's Granger causality patterns reflect a complex web of bidirectional relationships between REC, EPU, INSTQ, and FD. REC is found to be affected by TRADE, while FDI influences REC. Interestingly, EPU promotes FDI, and TRADE is influenced by both REC and INSTQ, highlighting the intricate linkages between these variables in the Sri Lankan context.

Table 8. Brief scenario of Long-run Granger-Causality

Causal Relationships as per Model	Bangladesh	Bhutan	India	Maldives	Nepal	Pakistan	Sri Lanka
REC vs. EPU	REC → EPU	REC → EPU	REC → EPU	REC → EPU	REC → EPU	REC ←→ EPU	REC → EPU
REC vs. INSTQ	REC → INSTQ	REC → INSTQ	REC → INSTQ	REC → INSTQ	REC → INSTQ	REC → INSTQ	REC → INSTQ
REC vs. TRADE	REC → TRADE	NA	NA	NA	REC → TRADE	REC → TRADE	REC → TRADE
REC vs. FDI	REC → FDI	NA	REC → FDI	REC → FDI	NA	NA	NA
REC vs. FD	REC → FD	NA	REC → FD	NA	NA	NA	REC → FD
EPU vs. INSTQ	EPU → INSTQ	EPU → INSTQ	EPU → INSTQ	EPU → INSTQ	EPU → INSTQ	EPU → INSTQ	EPU → INSTQ
EPU vs. TRADE	EPU → TRADE	NA	NA	NA	NA	NA	NA
EPU vs. FDI	NA	EPU → FDI	NA	EPU → FDI	EPU → FDI	NA	NA
EPU vs. FD	EPU → FD	NA	NA	NA	NA	NA	EPU → FD
INSTQ vs. TRADE	INSTQ → TRADE	NA	NA	NA	NA	NA	INSTQ → TRADE
INSTQ vs. FDI	INSTQ → FDI	INSTQ → FDI	INSTQ → FDI	INSTQ → FDI	NA	INSTQ → FDI	NA
INSTQ vs. FD	NA	NA	INSTQ → FD	NA	NA	NA	INSTQ → FD
TRADE vs. FDI	TRADE → FDI	TRADE → FDI	NA	NA	NA	NA	NA
TRADE vs. FD	NA	NA	NA	NA	NA	NA	NA
FDI vs. FD	FDI → FD	NA	FDI → FD	NA	NA	NA	NA

Notes: → indicates unidirectional causality in the long run, ←→ indicates bidirectional causality in the long run, and NA signifies no significant long-run Granger-causality between the variables.

The long-run Granger-causality analysis in Table 8 highlights the pivotal role of economic recovery, INSTQ, and EPU in shaping long-term economic and financial outcomes across South Asian countries. REC consistently influences key variables such as EPU, INSTQ, TRADE, and FD, highlighting its importance in driving economic stability and fostering institutional reforms. EPU affects INSTQ and FDI in several countries, reflecting the significance of policy certainty for governance and attracting long-term investments. INSTQ emerges as a critical driver of trade, FDI, and FD, emphasizing the need for strong institutions to sustain economic openness and build robust financial systems. FDI contributes to FD, particularly in Bangladesh, Bhutan, and India, while trade exhibits more limited long-run effects. Country-specific variations show Bangladesh and India as highly interconnected systems, while Bhutan, the Maldives, Nepal, and Pakistan rely on selective channels like REC and EPU for growth. The findings reveal the need for countries to strengthen economic recovery, enhance INSTQ, and ensure policy stability to achieve sustained development. The interconnectedness of these variables highlights the potential benefits of regional policy coordination for shared economic growth.

The findings suggest significant interactions and dynamics between these variables, indicating a complex scenario that impacts the adoption of renewable energy sources in the region. It highlights the importance of stable economic policies and institutional frameworks in promoting REC. Strong institutions and trade integration are found to have a positive impact on REC, signaling the need for supportive governance structures and open markets to facilitate the transition toward sustainable energy sources. Foreign investment also plays a vital role in driving renewable energy growth, emphasizing the importance of capital inflows and expertise in the sector.

The short-term impacts reveal that policy uncertainty can both incentivize and deter investments in renewable energy, showing the sensitivity of the sector to regulatory uncertainties. This impact is similar to the research outcome of Chowdhury and Chowdhury (2022). This study illustrates the varying effects of FD on REC, with some countries showing positive relationships while others exhibit negative dynamics, stressing the vital nature of financial sector influence on renewable energy adoption.

4.1. Policy Implications

Maximizing the renewable energy potential in South Asia requires policy measures closely aligned with the country-specific findings of this research. Recognizing the unique challenges and opportunities across the region, tailored strategies must be developed to address the distinct contexts of each country while promoting a cohesive regional approach to clean energy adoption.

4.1.1 Country-Specific Policy Implications

Strengthening INSTQ is critical for enhancing the efficiency and transparency of renewable energy projects across South Asia. For example, in Bangladesh, this can be achieved by promoting regional trade integration to facilitate the import of renewable energy equipment and cross-border energy sharing, supported by targeted financial incentives like tax breaks and subsidies to attract private sector investment in clean energy technologies. Bhutan, with its strong institutional framework, can foster collaborations in regional energy trade, particularly hydropower, while prioritizing the attraction of FDI for advanced renewable energy technologies and the development of green financial instruments to mobilize local and international investments. In India, addressing policy uncertainty through long-term, stable renewable energy policies is essential for building investor confidence. Concurrently, investments in upgrading grid infrastructure are crucial for handling the integration of variable renewable energy sources like solar and wind, with public-private partnerships (PPPs) playing a vital role in executing large-scale renewable energy projects.

In the Maldives, renewable energy investments should align with the country's vulnerability to climate change, focusing on technologies such as solar and ocean energy. Strengthened financial mechanisms are necessary to provide affordable financing options for small-scale renewable energy initiatives, while streamlined regulatory processes can expedite project approvals and ensure effective implementation. Nepal must prioritize institutional reforms to attract international funding for renewable energy projects and develop infrastructure for cross-border electricity trade to capitalize on its hydropower potential. Capacity-building programs are also vital to enhance local expertise in renewable energy technologies.

Pakistan can address its financial constraints by partnering with international institutions to secure affordable financing for renewable energy projects, coupled with improved policy consistency and transparency to attract foreign and domestic investment. Upgrading grid infrastructure is essential to accommodate renewable energy generation and ensure efficient distribution. In Sri Lanka, enhancing INSTQ can support the scaling up of renewable energy initiatives. Grid modernization is crucial for integrating renewable energy sources effectively, and robust land acquisition laws alongside transparent regulatory frameworks can reduce project delays and encourage private sector participation.

4.1.2 Regional Policy Implications

South Asia's transition to renewable energy requires coordinated efforts to address shared challenges and leverage collective strengths. Establishing cross-border energy trade agreements can optimize resource allocation and enhance energy security. Collaborative research and development (R&D) initiatives are needed to address technical barriers, such as grid integration and energy storage solutions. Regional financial mechanisms, such as pooled funds or joint ventures, can attract international investments and reduce financial risks. Aligning renewable energy policies across countries will create a consistent and attractive investment environment.

4.1.3 Overarching Measures

Infrastructure development is a priority, with grid systems requiring upgrades and modernization to handle renewable energy integration while minimizing energy losses. Capacity-building initiatives can provide training and technical support to local stakeholders, enhancing expertise in renewable energy planning and implementation. Regulatory reforms, including simplified bureaucratic processes, transparent project approval mechanisms, and strengthened enforcement, are vital to boost investor confidence. Finally, leveraging green financial instruments like green bonds, renewable energy funds, and international climate finance can secure the capital needed for large-scale clean energy projects.

5. Conclusion

This study has shed light on the intricate relationship between EPU and REC in South Asian nations. We examined the influence of INSTQ, TRADE, FDI, and FD on this dynamic. The findings reveal a multifaceted picture. While stable economic policies and robust institutions consistently promote long-term growth of energy consumption across the region, the short-term impact of policy uncertainty presents a nuanced challenge. It can act as both an incentive and a deterrent to investment, depending on the specific country context. Similarly, the influence of FD on REC varies by nation, underlining the need for a multi-pronged approach. Unlocking a cleaner future for South Asia necessitates a comprehensive strategy. Strengthening institutions through transparent regulations and streamlined governance, as exemplified by Bangladesh, will attract investment and accelerate renewable energy project development. Enhancing trade integration, similar to potential partnerships between the Maldives and India, facilitates access to cutting-edge technologies and best practices. Encouraging FDI requires targeted incentives, such as those Sri Lanka could offer for renewable energy specialists. Creating a stable policy environment with long-term outlooks, akin to what Nepal could implement, reduces risk and fosters long-term planning. Finally, enhancing FD through green financing mechanisms, like Pakistan emulating Bangladesh's renewable energy refinancing scheme, unlocks crucial capital for investment. Regional collaboration on a South Asian green investment fund could further mobilize resources. By adopting these comprehensive policy measures, South Asia can unlock its immense potential for renewable energy development, charting a course toward a sustainable and prosperous future for the region.

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