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Examining the Asymmetric Effects of Renewable Energy Use, Financial Development, and Trade Openness on Economic Growth in D-8 Islamic Countries

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ABSTRACT

This study investigates the asymmetric impacts of financial development, renewable energy consumption, and trade openness on economic growth in D-8 Islamic countries from 1970 to 2022, using advanced panel data techniques. The findings reveal long-run equilibrium relationships, with financial development and trade openness positively affecting gross domestic product (GDP) growth, while renewable energy exhibits an unexpected negative coefficient. The non-linear autoregressive distributed lag estimates uncover asymmetries, with larger GDP contractions from downside shocks in financial development and trade openness. Renewable energy shows growth penalties from negative changes but symmetric upside benefits. The results highlight the importance of well-developed financial systems, strategic renewable investments, and trade integration for sustainable growth. Policymakers should focus on financial reforms, renewable project facilitation, and reducing trade barriers, considering asymmetric impacts. This study contributes novel empirical evidence on asymmetric dynamics among these variables in D-8 countries, extending the literature through recent non-linear panel modeling techniques and demonstrating the merits of accounting for asymmetries. The combination of methods offers a robust and fresh perspective.

Keywords: D-8 Islamic Countries, Economic Growth, Financial Development, Renewable Energy, Trade Openness
JEL Classification: O47, B23

1. INTRODUCTION

The global energy landscape has undergone a profound transformation in recent years, driven by the urgent need to address climate change and reduce greenhouse gas emissions. As a result, renewable energy sources have emerged as a critical component of the energy mix, offering a sustainable and environmentally friendly alternative to fossil fuels. The transition towards renewable energy has become a priority for many countries, including the members of the D-8 organization for economic cooperation, a prominent group of eight developing Islamic nations (Bangladesh, Egypt, Indonesia, Iran, Malaysia, Nigeria, Pakistan, and Turkey). The D-8 countries have experienced significant economic growth in recent decades, fueled by their abundant natural resources, growing populations, and expanding trade relations. However, this growth has come at a cost, with increasing energy demand and associated environmental challenges. The reliance on traditional fossil fuels has exacerbated these issues, highlighting the need for a shift towards more sustainable energy sources (Işık et al., 2021; Ren et al., 2022). Renewable energy sources, such as solar, wind, hydroelectric, and geothermal, offer a promising solution to address these challenges. Not only do they contribute to mitigating climate change and reducing greenhouse gas emissions, but they also promote energy security, diversify the energy mix, and create new economic opportunities (Akadiri et al., 2021; Shahbaz et al., 2022). Despite the potential benefits of renewable energy, its adoption and integration into the energy systems of the D-8 countries have been hindered by several factors. These include; inadequate financial resources and limited access to funding for renewable energy projects (Manzoor et al., 2021; Shahbaz et al., 2022), lack of robust policies and regulatory frameworks to support and incentivize renewable energy investments (Akadiri et al., 2021; Rafindadi and Ozturk, 2017), technical challenges associated with integrating renewable energy sources into existing grid infrastructure (Işık et al., 2021; Ren et al., 2022), and dependence on fossil fuel subsidies and vested interests in traditional energy sectors (Manzoor et al., 2021; Shahbaz et al., 2022). However, the transition towards renewable energy sources is not only an environmental imperative but also carries significant economic implications. Numerous studies have investigated the relationship between renewable energy consumption and economic growth, yielding mixed and often conflicting results (Akadiri et al., 2021; Rafindadi and Ozturk, 2017; Shahbaz et al., 2022). Furthermore, the role of financial development and trade openness in mediating the relationship between renewable energy use and economic growth remains underexplored, particularly in the context of the D-8 Islamic countries. Financial development can facilitate access to capital and investment in renewable energy projects, while trade openness can promote the exchange of technology, knowledge, and best practices (Akadiri et al., 2021; Manzoor et al., 2021). This research aims to address these gaps by examining the asymmetric effects of renewable energy use, financial development, and trade openness on economic growth in the D-8 Islamic countries. By employing the panel non-linear autoregressive distributed lag (NARDL) approach, this study seeks to capture the potential non-linearities and asymmetries in the relationships between these variables.

2. EMPIRICAL LITERATURE REVIEW

The nexus between renewable energy consumption, financial development, trade openness, and economic growth has received considerable attention in the empirical literature, albeit with mixed and often conflicting findings. This section provides a critical review of the relevant empirical studies, highlighting the existing research gaps and the need for further investigation.

2.1. Renewable Energy Consumption and Economic Growth

Several studies have explored the relationship between renewable energy consumption and economic growth, yielding diverse results across different countries and regions. Some studies have found a positive and significant impact of renewable energy consumption on economic growth (Akadiri et al., 2021; Bhattacharya et al., 2016; Rafindadi and Ozturk, 2017), suggesting that the adoption of renewable energy sources can stimulate economic development through job creation, technological innovation, and reduced dependence on fossil fuel imports. However, other studies have reported a negative or insignificant relationship between renewable energy consumption and economic growth (Alola et al., 2021; Işık et al., 2021; Mert and Bölük, 2016). These findings may be attributable to the high initial costs of renewable energy projects, insufficient technological capabilities, and the dominance of traditional energy sources in the respective economies. While most existing studies have focused on the linear relationship between renewable energy consumption and economic growth, a growing body of literature has recognized the potential asymmetric effects of this relationship (Işık et al., 2021; Ren et al., 2022; Shahbaz et al., 2022). These studies have employed non-linear econometric approaches, such as the NARDL model, to capture the potential asymmetries. For instance, Işık et al. (2021) investigated the asymmetric effects of renewable energy consumption on economic growth in D-8 countries using the NARDL approach. Their findings revealed that positive shocks in renewable energy consumption had a significant positive impact on economic growth, while negative shocks had an insignificant effect. Similarly, Ren et al. (2022) found evidence of asymmetric effects, with positive changes in renewable energy consumption having a larger impact on economic growth compared to negative changes.

2.2. Financial Development and Renewable Economic Growth

Financial development plays a crucial role in facilitating the adoption and diffusion of renewable energy technologies by providing access to capital, investment opportunities, and financial instruments (Akadiri et al., 2021; Manzoor et al., 2021; Shahbaz et al., 2022). Well-developed financial systems can attract domestic and foreign investments in renewable energy projects, fostering economic growth and environmental sustainability. Several studies have explored the impact of financial development on renewable energy consumption, with mixed results. While some studies have found a positive and significant relationship (Manzoor et al., 2021; Shahbaz et al., 2022), others have reported an insignificant or negative relationship (Akadiri et al., 2021; Işık et al., 2021), potentially due to factors such as inefficient allocation of financial resources or the dominance of traditional energy sectors in the respective economies.

2.3. Trade Openness and Renewable Economic Growth

Trade openness can facilitate the diffusion of renewable energy technologies, knowledge, and best practices across borders (Akadiri et al., 2021; Manzoor et al., 2021; Shahbaz et al., 2022). Increased trade openness can promote the exchange of goods and services related to renewable energy, fostering technological transfer and enhancing competitiveness in the renewable energy sector. However, the empirical evidence on the relationship between trade openness and renewable energy consumption is mixed. Some studies have found a positive and significant impact of trade openness on renewable energy consumption (Manzoor et al., 2021; Shahbaz et al., 2022), while others have reported an insignificant or negative relationship (Akadiri et al., 2021; Işık et al., 2021), potentially due to factors such as trade barriers, lack of technology transfer, or the dominance of traditional energy exports in the respective economies.

2.4. Theoretical Framework

The theoretical foundation for this research draws upon several economic and energy-related theories, including the environmental Kuznets curve (EKC) hypothesis, the energy-led growth hypothesis, and the feedback hypothesis. The EKC hypothesis suggests that there is an inverted U-shaped relationship between economic growth and environmental degradation (Grossman and Krueger, 1991; Stern, 2004). In the initial stages of economic development, environmental degradation increases due to industrialization and the prioritization of economic growth over environmental concerns. However, as economies become more developed and shift towards service-based and knowledge-intensive industries, the demand for environmental quality increases, leading to a decline in environmental degradation (Ozturk, & Al-Mulali, 2015). Within the context of this research, the EKC hypothesis provides a theoretical basis for examining the relationship between renewable energy consumption and economic growth. As economies transition towards sustainable energy sources and adopt cleaner technologies, the environmental impact of energy consumption may decrease, aligning with the latter stages of the EKC hypothesis. The energy-led growth hypothesis postulates that energy consumption is a crucial input for economic growth and development (Apergis and Payne, 2010; Ozturk, 2010). According to this hypothesis, increased energy consumption, whether from conventional or renewable sources, can stimulate economic growth by enabling industrial production, transportation, and other economic activities. In the context of this research, the energy-led growth hypothesis supports the notion that increased renewable energy consumption may contribute to economic growth in the D-8 Islamic countries by providing a sustainable and reliable energy source for economic activities. The feedback hypothesis suggests a bidirectional causal relationship between energy consumption and economic growth (Ozturk, 2010; Stern, 2000). This hypothesis posits that energy consumption drives economic growth, while economic growth, in turn, leads to increased energy demand due to higher production levels and consumption patterns. Within the framework of this research, the feedback hypothesis implies that renewable energy consumption and economic growth may have a reciprocal relationship, where increased renewable energy consumption stimulates economic growth, and economic growth, in turn, incentivizes further investments in renewable energy technologies and infrastructure.

2.5. Research Gap

While numerous studies have delved into the interplay between renewable energy consumption, financial development, trade openness, and economic growth, several critical research gaps remain unaddressed. One notable gap is the limited attention given to the potential asymmetric effects of renewable energy consumption on economic growth, particularly in the context of the D-8 Islamic countries (Ren et al., 2022; Shahbaz et al., 2022). The existing literature has predominantly focused on linear relationships, failing to account for potential non-linearities and asymmetries in the impact of renewable energy consumption on economic growth. Furthermore, the role of financial development and trade openness in mediating the relationship between renewable energy consumption and economic growth warrants further investigation. Existing studies have yielded mixed and conflicting results, with some studies suggesting a positive mediating effect (Manzoor et al., 2021; Shahbaz et al., 2022), while others have reported an insignificant or negative impact (Akadiri et al., 2021; Işık et al., 2021). These conflicting findings highlight the need for a more nuanced and context-specific examination of the mediating roles of financial development and trade openness. Notably, most existing studies have employed linear econometric approaches, which may fail to capture the potential non-linearities and asymmetries in the relationships among renewable energy consumption, financial development, trade openness, and economic growth (Alola et al., 2021; Ren et al., 2022). The use of non-linear econometric techniques, such as the panel NARDL approach, can provide valuable insights into these complex and potentially asymmetric relationships. Moreover, there is a distinct lack of comprehensive studies focusing specifically on the D-8 Islamic countries, which possess unique economic, energy, and environmental characteristics (Işık et al., 2021; Ren et al., 2022). These countries have diverse socio-economic conditions, energy policies, and environmental challenges, necessitating a tailored analysis to inform effective policymaking and sustainable development strategies.

3. METHODOLOGY AND DATA OF THE STUDY

This study aims to investigate the asymmetric effects of financial development, renewable energy consumption, and trade openness on economic growth in the D-8 Islamic countries from 1970 to 2022. To achieve this objective, the research employs annualized time series data for the D-8 country panel, obtained from the World Bank's comprehensive data collection. The study draws upon the world development indicators -2024 database to source the relevant variables for the analysis. Economic performance is represented by the gross domestic product (GDP) growth rate, which serves as a widely accepted indicator of economic growth (Adebayo and Odugbesan, 2022; Destek and Sinha, 2023). To model the relationships between the variables of interest and economic growth, the study adopts the cobb-douglas production function framework. This widely utilized functional form allows for the incorporation of multiple inputs, including financial development, renewable energy consumption, and trade openness, and their respective impacts on economic output (Destek and Sinha, 2023; Shahbaz et al., 2023). The Cobb-Douglas production function model specified in the study can be represented as follows:

$$V_{it} = \mathrm{N}_{it}^{\rho} (T_{it} W_{it})^{1-\rho} \quad (1)$$

By employing the Cobb-Douglas production function model and incorporating the relevant variables, the study aims to capture the potential asymmetric effects of renewable energy consumption, financial development, and trade openness on economic growth in the D-8 Islamic countries (Adebayo and Odugbesan, 2022; Shahbaz et al., 2023). The study employs a panel data approach to enhance the robustness and reliability of the analysis. By transforming the sample data into a panel format, the researcher gains several advantages over traditional time series or cross-sectional data analysis. Panel data analysis offers a higher degree of freedom, allowing for more efficient estimation and more reliable inferences (Kamalu et al., 2019; Paramati et al., 2022). The increased degrees of freedom result from the combined cross-sectional and time-series dimensions, providing more informative data and reducing the risk of multicollinearity among the variables of interest. Moreover, panel data analysis accounts for unobserved heterogeneity across the D-8 Islamic countries, capturing country-specific characteristics that may influence the relationships between renewable energy consumption, financial development, trade openness, and economic growth (Shahbaz et al., 2023; Zaman et al., 2022). This heterogeneity is often challenging to capture in pure time series or cross-sectional data analyses. By adopting a panel data approach, the analytical model in this study can be specified as follows:

$$LGDP_{it} = \varphi_{0i} + \varphi_{1i}LFD_{it} + \varphi_{2i}\,LTOP_{it} + \varphi_{3i}\,LRE_{it} + \omega_{it} \qquad (2)$$

Where LFD_{it} indicated the financial development, $LTOP_{it}$ indicated the trade openness; $LREit$ indicated the renewable energy and ω_{it} is an error term.

3.1. Testing Slope Homogeneity and Cross-sectional Dependency Test

The issue of parameter heterogeneity is a critical consideration in panel data analysis. It addresses the question of whether the slope coefficients, which capture the relationships between the independent variables and the dependent variable, are consistent across the cross-sectional units (in this case, the D-8 Islamic countries) or exhibit heterogeneity. The presence of parameter heterogeneity can have significant implications for the interpretation and reliability of the estimated coefficients. A common approach to testing for parameter homogeneity is through the use of Hausman-type tests, such as the F-test or the swamy test (Destek and Sinha, 2023; Shahbaz et al., 2023). These tests typically involve a strong null hypothesis that posits the homogeneity of slope coefficients across the panel. In other words, the null hypothesis assumes that the relationships between the independent variables (renewable energy consumption, financial development, and trade openness) and the dependent variable (economic growth) are identical across all cross-sectional units (Paramati et al., 2022; Zaman et al., 2022). However, it is essential to consider the specific characteristics and heterogeneity present within the D-8 Islamic countries. These countries may exhibit distinct economic, energy, and environmental profiles, which could potentially violate the assumption of parameter homogeneity (Adebayo and Odugbesan, 2022; Shahbaz et al., 2023). Imposing a homogeneity assumption in such cases may fail to capture the unique characteristics and dynamics within each country. Furthermore, the applicability of the F-test and swamy test in panel data analysis is contingent on the relative size of the cross-sectional dimension (N) compared to the time-series dimension (T) (Destek and Sinha, 2023; Paramati et al., 2022). These tests are typically more reliable when the number of cross-sectional units (N) is relatively small compared to the time-series length (T).

$$\pi_{it} = \tau_i + \vartheta_i y_{it} + \sigma_{it} \qquad (3)$$

The CD test is as follows:

$$CD = \sqrt{\frac{2\pi}{\gamma(\gamma-1)}\sum_{i=1}^{\gamma-1}\sum_{j=i+1}^{\gamma}\hat{\aleph}_{ij}} \qquad (4)$$

Where $\hat{\aleph}_{ij}$ is the unpretentious evaluation of the Pair-wise correlation of the residuals.

$$\hat{\aleph}_{ij} = \hat{\aleph}_{ij} = \frac{\sum_{\rho=1}^{\tau}\varepsilon_{ij}\varepsilon_{ij}}{\left(\sum_{\rho=1}^{\tau}\varepsilon_{i\rho}^{2}\right)^{1/2}\left(\sum_{\rho=1}^{\tau}\varepsilon_{j\rho}^{2}\right)^{1/2}} \qquad (5)$$

and ε_{ij} is the ordinary least square estimate of σ_{it} in equation (5) above, it is defined as

$$\varepsilon_{it} = \pi_{it} - \hat{\tau}_i - \hat{\vartheta}_i\, y_{it} \qquad (6)$$

3.2. Panel Unit Root Test

Determining the order of integration of the variables is a crucial step in panel data analysis, as it ensures the appropriate estimation techniques and avoids spurious regression results. To address this, the study employs two second-generation panel unit root tests: The cross-sectionally augmented Im, Pesaran, and Shin (CIPS) test and the cross-sectionally augmented Dickey-Fuller (CADF) test. These second-generation panel unit root tests are designed to account for cross-sectional dependence, a common issue in panel data analysis where shocks or disturbances in one cross-sectional unit may influence other units (Adebayo and Odugbesan, 2022; Paramati et al., 2022). Failure to account for cross-sectional dependence can lead to size distortions and erroneous inferences. The CIPS and CADF tests are based on the null hypothesis that all panels (in this case, the D-8 Islamic countries) contain a unit root, which implies non-stationarity of the variables (Destek and Sinha, 2023; Shahbaz et al., 2023). Rejecting the null hypothesis suggests that the variables are stationary, either in levels or after taking first or higher-order differences. Establishing the order of integration is crucial for several reasons:

1. It guides the selection of appropriate estimation techniques, such as cointegration analysis or the panel ARDL approach, which require certain assumptions about the order of integration of the variables.
2. It ensures that the estimated relationships are not spurious, as regressing non-stationary variables on each other can lead to misleading inferences.

3. It informs the choice of appropriate data transformations (e.g., differencing) if the variables are found to be non-stationary in levels.

By conducting these panel unit root tests and determining the order of integration, the study establishes a solid foundation for the subsequent analysis of the asymmetric effects of renewable energy consumption, financial development, and trade openness on economic growth in the D-8 Islamic countries. This process measures the p-values paired which can be stated as follows:

$$Y_{i,t} = (1-\varphi_i)\alpha_i + \varphi_i y_{i,t-1} + \pi_{i,t} i = 1,2,3,\ldots\ldots\ldots, N \text{ and } t = 1,2,3,\ldots\ldots\ldots,T \quad (7)$$

$$\pi_{it} = \gamma_i f_t + \mu_{it} \quad (8)$$

Here f_t displays unobservable prevalent influence of each country, μ_{it} reveals the error of individual-specific. Equation (1) and (2), as well as unit root hypothesis, can be given as follows:

$$\Delta y_{it} = \delta_i + \beta y_{i,t-1} + \tau_i f_t + \mu_{it}\ i = 1,2,3,\ldots\ldots.,N \text{ and } t = 1,2,3,\ldots\ldots.,T \quad (9)$$

H_0: $\beta_i = 0$ *upon all i (non-stationarity)*
H_1:$\beta_i < 0 i = 1,2,3,\ldots.,N_1 \beta_i = oi = N_1 + 1, N_1 + 2\ldots\ldots\ldots,N$.
(*the series is stationary)*

3.3. Panel Cointegration Test

To test for cointegration between the variables in the panel data framework, this study employs the residual-based panel cointegration test proposed by Pedroni (1999, 2004). This test offers several advantages for analyzing heterogeneous panels where the true cointegrating vectors may vary across cross-sectional units (Shahbaz, et al., 2018).

Specifically, Pedroni's test provides seven test statistics categorized into two groups:

1. Within-dimension tests: These pool the residuals across the entire panel to test for cointegration, including panel v-statistic, panel rho-statistic, panel PP-statistic, and panel ADF-statistic.
2. Between-dimension tests: These are group-mean tests that average individual unit root test statistics for each cross-sectional unit, including group rho-statistic, group PP-statistic, and group ADF statistic.

As Pedroni (2001) notes, an important advantage of the between-dimension group-mean tests is that in the presence of heterogeneous cointegrating vectors, the group-mean statistics provide a more meaningful interpretation of the estimated coefficients.

Hence, this study utilizes both the panel/within-dimension tests and the group/between-dimension tests proposed by Pedroni (1999, 2004). The null hypothesis for all seven test statistics is no cointegration. Rejection of the null implies the existence of cointegration between renewable energy consumption, financial development, trade openness, and economic growth for the D-8 panel.

By using Pedroni's comprehensive panel cointegration testing approach, this study accounts for potential heterogeneity in the panel while investigating the long-run equilibrium relationships between the variables of interest.

Panel ε-statistic:

$$Q_\varepsilon = \left(\sum_{i=1}^{\gamma}\sum_{t=1}^{\delta}\hat{R}_{11i}^{-2}\hat{\aleph}_{it-1}^{2}\right)^{-1} \quad (10)$$

Panel τ –statistic:

$$Q_\tau = \left(\sum_{i=1}^{\gamma}\sum_{t=1}^{\delta}\hat{R}_{11i}^{-2}\hat{\aleph}_{it-1}^{2}\right)^{-1}\sum_{i=1}^{\gamma}\sum_{t=1}^{\delta}\hat{R}_{11i}^{-2}(\hat{\aleph}_{it-1}\Delta\hat{\aleph}_{it} - \hat{\rho}_i) \quad (11)$$

Panel PP-statistic:

$$Q_\tau = \left(\hat{\omega}^2\sum_{i=1}^{\gamma}\sum_{t=1}^{\delta}\hat{R}_{11i}^{-2}\hat{\aleph}_{it-1}^{2}\right)^{-1/2}\sum_{i=1}^{\gamma}\sum_{t=1}^{\delta}\hat{R}_{11i}^{-2}(\hat{\aleph}_{it-1}\Delta\hat{\aleph}_{it} - \hat{\rho}_i) \quad (12)$$

Panel ADF-statistic:

$$Q_\tau^* = \left(\hat{Z}^{*2}\sum_{i=1}^{\gamma}\sum_{t=1}^{\delta}\hat{R}_{11i}^{-2}\hat{\aleph}_{it-1}^{*2}\right)^{-1/2}\sum_{i=1}^{\gamma}\sum_{t=1}^{\delta}\hat{R}_{11i}^{-2}\hat{\aleph}_{it-1}^{*2}\Delta\hat{\aleph}_{it}^{*2} \quad (13)$$

Group ρ–statistic:

$$\tilde{Q}_\tau = \sum_{i=1}^{\gamma}\left(\sum_{t=1}^{\delta}\hat{\aleph}_{it-1}^{2}\right)^{-1}\sum_{t=1}^{T}(\hat{\aleph}_{it-1}\Delta\hat{\aleph}_{it} - \hat{\rho}_i) \quad (14)$$

Group PP-statistic:

$$\tilde{Q}_\tau = \sum_{i=1}^{\gamma}\left(\hat{\sigma}^2\sum_{t=1}^{\delta}\hat{\aleph}_{it-1}^{2}\right)^{-1/2}\sum_{t=1}^{\delta}(\hat{\aleph}_{it-1}\Delta\hat{\aleph}_{it} - \hat{\rho}_i) \quad (15)$$

Group ADF-statistic:

$$\tilde{Q}_t^* = \sum_{i=1}^{\gamma}\left(\hat{\sigma}^2\sum_{t=1}^{\delta}\tilde{Z}_t^2\hat{\aleph}_{it-1}^{*2}\right)^{-1/2}\sum_{t=1}^{\delta}(\hat{\aleph}_{it-1}^{*} - \hat{\aleph}_{it}^{*2}) \quad (16)$$

The panel cointegration test proposed by Pedroni (1999, 2004) differs from the system cointegration test of Larsson et al. (2001) in its treatment of the number of cointegrating vectors. Specifically, Larsson et al. system approach allows for testing cointegration in panels with multiple cointegrating vectors. This allows greater flexibility in modeling potentially complex cointegrating relationships between variables. In contrast, Pedroni's residual-based panel cointegration test is designed under the assumption of a single cointegrating vector existing between the variables of interest. This imposes a more restrictive condition on the nature of cointegrating relationships able to be detected. Accordingly, the null hypothesis under Pedroni's test reflects this assumed specification of a maximum one cointegrating relationship:

H_0: No cointegrating relationship (the assumed single cointegrating vector is absent)

While capable of indicating evidence of some comovement between non-stationary variables, rejection of the null here would strictly imply the presence of the posited single vector. It does not preclude additional, unaccounted for vectors emerging in a less constrained specification like Larsson et al. systems approach. Therefore, when applying Pedroni's popular panel test, it is important to consider the limitations of its single vector assumption in adequately representing complex real-world variable dynamics. Augmenting findings with less restrictive procedures can provide deeper insights and confidence regarding detected cointegrating associations.

$$LLL^S\left(k/x\right)=\frac{\sqrt{N^2\sum_{i=1}^{N}\left(LR_i^v\left(k/x\right)-E(LR_i^v\left(k/x\right))\right)}}{\sqrt{Var\left(LR_i^v\left(k/x\right)\right)}}\rightarrow N\left(0,1\right) \tag{17}$$

The analysis of cointegration in panel data frameworks has evolved from first generation techniques, such as those proposed by Pedroni (1999, 2004), Kao (1999), and Larsson et al. (2001), to more recent second-generation procedures. While valuable, these earlier tests suffer from limitations related to cross-sectional dependence and heterogeneity that can undermine their reliability (Samadi et al., 2020; Solarin et al., 2020). To mitigate these issues, contemporary research increasingly relies on second generation cointegration tests, such as those developed by Westerlund (2007) and Westerlund and Edgerton (2007). A distinguishing advantage of these later tests is the accommodation for dependence across cross-sectional units through the inclusion of common time factors (Paramati et al., 2022; Samadi et al., 2023). Furthermore, by permitting correlation in the residuals via bootstrapping, more powerful inferences robust to heterogeneity are enabled (Solarin et al., 2020). Therefore, in conjunction with conventional first-generation panel cointegration tests, this study augments the long-run analysis through the incorporation of methods proposed in Westerlund (2007) and Westerlund and Edgerton (2007). This combination of traditional and contemporary techniques provides deeper assurance regarding the validity of detected equilibrium relationships between renewable energy consumption, financial development, trade openness, and economic growth in the sample panel. These include two group mean statistics $G\tau$ and $G\alpha$ which test if cointegration exists for at least one panel member. Specifically, $G\tau$ averages the individual τi statistics that capture the lack of error correction, while $G\alpha$ averages the individual error correction term (ectt-1) coefficients αi. Mathematically, these group mean statistics are calculated as follows:

$$G_\tau=\frac{1}{\tau}\sum_{i=1}^{\tau}\frac{\breve{\alpha}_i}{Se(\breve{\alpha}_i)} \tag{18}$$

$$G_\alpha=\frac{1}{\tau}\sum_{i=1}^{\tau}\frac{T\breve{\alpha}_i}{1-\sum_{j=1}^{m}\breve{\alpha}_{ij}} \tag{19}$$

Statistics for $P\tau$ and $P\alpha$ are used to determine if the whole panel has cointegration and are given in eqs. (18) and (19):

$$P_\tau=\frac{\breve{\alpha}}{Se(\breve{\alpha})} \tag{20}$$

$$P_\alpha=T\breve{\alpha} \tag{21}$$

where τi and αi are the individual statistics, αi is the ectt-1 coefficient for unit i as mentioned, and N is the total number of cross-sections. The other two panel statistics $P\tau$ and $P\alpha$ pool information across the units to determine if cointegration exists for the whole panel. By combining both the group mean and panel test statistics, Westerlund's approach provides comprehensive evidence on the long-run relationship between variables.

3.4. The Panel ARDL Test

To examine the long-run and short-run symmetric relationships between renewable energy consumption, financial development, trade openness, and economic growth in the D-8 countries, this study employs the pooled mean group (PMG) estimator proposed by Pesaran et al. (1999). Initially, the analysis assumes symmetric effects from the explanatory variables on economic growth to provide a useful baseline scenario. The PMG estimator allows for a degree of heterogeneity in the short-run coefficients and error variances across the D-8 countries while restricting the long-run coefficients to be equal. This imposes a certain degree of homogeneity consistent with the panel structure of the data. Estimation under the PMG framework requires some key assumptions to produce consistent and efficient parameter estimates:

1. The ectt-1 is free of serial correlation and normally, identically distributed based on the regressor set, indicating they can be treated as exogenous.
2. A long-run cointegrating relationship exists between the dependent variable (economic growth) and the set of explanatory variables (renewable energy consumption, financial development, trade openness).
3. The long-run coefficients remain constant across the cross-sectional D-8 units, while intercepts, short-run coefficients, and error variances are panel-specific.

These conditions provide validity for modeling under the linear ARDL specification proposed by Pesaran et al. (1999) for panel data:

$$P_{it} = \sum_{j=1}^{r} \varphi_{ij} p_{i,t-j} + \sum_{j=1}^{r} \vartheta_{ij} s_{i,t-j} + \tau_i + \omega_{it} \quad (22)$$

To investigate both the short-run and long-run symmetric relationships in the panel, this study employs several cutting-edge econometric techniques suitable for heterogeneous panels. Initially, the MG estimator (Pesaran and Smith 1995) and PMG estimator (Pesaran et al. 1999) are applied. The MG estimator permits full heterogeneity in all estimated parameters across cross-sectional units. In contrast, the PMG estimator restricts the long-run coefficients to be identical but allows short-run dynamics and error variances to differ. To determine the appropriate modeling approach, a Hausman-type test examines the null hypothesis that no significant differences exist between the MG and PMG estimators. Failure to reject this null hypothesis implies the long-run homogeneity imposed by the PMG framework cannot be rejected, and the PMG will yield more efficient and consistent parameter estimates for the panel data structure. The results of this statistical specification testing confirm the validity of utilizing the PMG estimator based on maximum likelihood for further analysis. By exploiting both the dynamic and heterogeneous aspects of the data, the PMG approach is well-equipped to capture the complex symmetric relationships between renewable energy usage, financial development, trade openness, and economic growth across the D-8 countries.

$$\Delta LGDP_{it} = \beta_1 + \sum_{j=1}^{p-1} \partial_{ij} \Delta LGDP_{it-j} + \sum_{1=0}^{q-1} \gamma_{ij} \Delta LFD_{ij-1}$$
$$+ \sum_{1=0}^{r-1} \delta_{ij} \Delta LTOP_{ij-1} + \sum_{1=0}^{s-1} \varphi_{ij} \Delta LRE_{ij-1} + \pi_1 LGDP_{ij-1}$$
$$+ \pi_2 LNFD_{ij-1} + \pi_3 LTOP_{ij-1} + \pi_4 LNRE_{ij-1} + + \mu_{1it} + \varepsilon_{1it} \quad (23)$$

Where: is the first difference operator, and LGDP, LFD, LTOP, LRE, are the four variables selected in the study. The constant is β_1 the short-run and long-run coefficients on the trends are $\partial_{ij}, \gamma_{ij}, \delta_{ij}$ *and* φ_{ij} *and* $\pi_1, \pi_2 \pi_3$ *and* π_4 respectively. *p,q,r,s and z* represents the maximum lag length, ε_{1it}, ε_{2it}, ε_{3it}, and ε_{4it} are error terms.

3.5. The Asymmetric Panel ARDL

To examine potential asymmetric relationships between the variables, this study employs recent advances in non-linear panel data modeling. Unlike linear symmetric frameworks which constrain positive and negative changes in explanatory variables to have identical effects, asymmetric modeling allows differential impacts from positive and negative "shocks" to key predictors. Specifically, building on the flexible panel data methods proposed by Shin et al. (2014), the previously specified baseline models can be adapted by separately parameterizing positive and negative partial sums of first-differenced regressors. This decomposition of explanatory variable changes into their positive and negative components provides the capacity to detect whether and where distinct effects may emerge. By extending the empirical framework to accommodate asymmetric specifications, this research can uncover important nuances regarding how upside and downside shifts in renewable energy consumption, financial development, and trade openness may exert distinct effects on economic growth across D-8 countries over time. The resulting asymmetric equation, as formulated by Shin et al. (2014), can be expressed as:

$$\Delta LGDP_{it} = \varphi_{0i} + \varphi_{1i} LGDP_{i,t-1} + \varphi_{2i}^{+} FD_{t-1}^{+}$$
$$+ \varphi_{2i}^{-} FD_{t-1}^{-} + \varphi_{3i}^{+} TOP_{t-1}^{+} + \varphi_{3i}^{-} TOP_{t-1}^{-} + \varphi_{4i}^{+} RE_{t-1}^{+}$$
$$+ \varphi_{4i}^{-} RE_{t-1}^{-} + \sum_{j=1}^{Q} \tau_{ij} LGDP_{i,t-1}$$

$$+ \sum_{j=0}^{Q} \left(\tau_{ij}^{+} FD_{t-j}^{+} + \tau_{ij}^{-} FD_{t-j}^{-} \right) + \sum_{j=0}^{Q} \left(\sigma_{ij}^{+} TOP_{t-j}^{+} + \sigma_{ij}^{-} TOP_{t-j}^{-} \right)$$
$$+ \sum_{j=0}^{Q} \left(\rho_{ij}^{+} RE_{t-j}^{+} + \rho_{ij}^{-} RE_{t-j}^{-} \right) + \omega_{it} \quad (24)$$

Where TOP^{+} and TOP^{-} stand for the positive and negative shock of trade openness, FD^{+} and FD^{-} stand for the positive and negative shock of financial development, RE^{+} and RE^{-} stand for the positive and negative shock of renewable energy consumption. The long-run coefficients are computed as $FD^{+} = \frac{-\varphi_{2i}^{+}}{\varphi_{1i}}, FD^{-} = \frac{-\varphi_{2i}^{-}}{\varphi_{1i}}, TOP^{+} = \frac{-\varphi_{3i}^{+}}{\varphi_{1i}},$ $TOP^{-} = \frac{-\varphi_{3i}^{-}}{\varphi_{1i}}, RE^{+} = \frac{-\varphi_{4i}^{+}}{\varphi_{1i}}, RE^{-} = \frac{-\varphi_{4i}^{-}}{\varphi_{1i}}$, respectively.

$$\begin{cases} FD_i^{+} = \sum_{k-1}^{t} \Delta FD_{ik}^{+} + \sum_{K-1}^{T} MAX(\Delta FD_{ik}, 0 \\ FD_i^{-} = \sum_{k-1}^{t} \Delta FD_{ik}^{-} + \sum_{K-1}^{T} MIN(\Delta FD_{ik}, 0 \end{cases}$$

$$\begin{cases} TO_i^{+} = \sum_{k-1}^{t} \Delta TOP_{ik}^{+} + \sum_{K-1}^{T} MAX(\Delta TOP_{ik}, 0 \\ TOP_i^{-} = \sum_{k-1}^{t} \Delta TOP_{ik}^{-} + \sum_{K-1}^{T} MIN(\Delta TOP_{ik}, 0 \end{cases}$$

$$\begin{cases} RE_i^{+} = \sum_{k-1}^{t} \Delta RE_{ik}^{+} + \sum_{K-1}^{T} MAX(\Delta RE_{ik}, 0 \\ RE_i^{-} = \sum_{k-1}^{t} \Delta RE_{ik}^{-} + \sum_{K-1}^{T} MIN(\Delta RE_{ik}, 0 \end{cases}$$

The error correction is as follows:

The equation $\sum_{i=0} \vartheta_i^{+}$ explores the possible effect of fluctuations in macroeconomic variables, while $\sum_{i=0} \gamma_i^{-}$ processes the short-run effects on and financial creation of fluctuations in macroeconomic variables. Consequently, the asymmetric short-run impact variations of financial development fluctuations of macroeconomic variables are often taken into account in this arrangement along with asymmetric long-run relationships. The model for error correction (ECM) of the previous equation is described as:

$$\Delta LGDP_{it} = \theta_{0i}\varepsilon_{it-1} + \sum_{j=1}^{Q}\tau_{ij} LGDP_{i,t-1} + \sum_{j=0}^{Q}(\tau_{ij}^{+} FD_{t-j}^{+} + \tau_{ij}^{-} FD_{t-j}^{-}) + \sum_{j=0}^{Q}(\sigma_{ij}^{+} TOP_{t-j}^{+} + \sigma_{ij}^{-} TOP_{t-j}^{-}) + \sum_{j=0}^{Q}(\rho_{ij}^{+} RE_{t-j}^{+} + \rho_{ij}^{-} RE_{t-j}^{-}) + \omega_{it} \quad (25)$$

3.6. Panel Granger Causality Estimates

The causal relationship is calculated using a fully modified ordinary least squares (FMOLS) for heterogeneous co-integrated panels developed by Pedroni (2000) when a long-run co-integrated relationship exists between $LGDP_{it}$, LFD_{it}, $LTOP_{it}$ and LRE_{it}. This approach is focused on an interdimensional estimator that takes heterogeneity throughout countries into account. This is selected because the mode in which the data is pooled allows greater versatility in the presence of co-integrating vector heterogeneity. The point estimate for the interdimensional estimator can be interpreted as the mean value of the co-integrating vector, according to Pedroni (2000). Consider, therefore, the regression:

$$LGDP_{it} = \gamma_i + \delta_{1i} LFD_{it} + \delta_{2i} LTOP_{it} + \delta_{3i} LRE_{it} + \mu_{it} \quad (26)$$

$$LFD_{it} = \gamma_i + \delta_{1i} LGDP_{it} + \delta_{2i} LTOP_{it} + \delta_{3i} LRE_{it} + \mu_{it} \quad (27)$$

$$LTOP_{it} = \gamma_i + \delta_{1i} LGDP_{it} + \delta_{2i} LFD_{it} + \delta_{3i} LRE_{it} + \mu_{it} \quad (28)$$

$$LRE_{it} = \gamma_i + \delta_{1i} LGDP_{it} + \delta_{2i} LFD_{it} + \delta_{3i} LTOP_{it} + \mu_{it} \quad (29)$$

Where $LGDP_{it}, LFD_{it}, LTOP_{it}$ *and* LRE_{it} are cointegrated with slopes δ_{1i}, δ_{2i}, *and* δ_{3i}

the group-mean panel FMOLS estimator is given as:

$$\hat{\delta}_{GFM}^{*} = N^{-1}\sum_{i=1}^{N}\hat{\delta}_{GFM,i}^{*} \quad (30)$$

The associated t-statistic for the between dimension-estimator is given as:

$$t\hat{\delta}_{GFM}^{*} = N^{-1/2}\sum_{i=1}^{N} t\hat{\delta}_{GFM.i}^{*} \quad (31)$$

Where $t\hat{\delta}_{GFM}^{*}$ is the associated t-value from the individual FMOLS ESTIMATES?

3.7. Dumitrescu and Hurlin Heterogeneous panel granger causality

This paper also used Dumitrescu and Hurlin heterogeneous panel granger causality to determine the causal link betwenn the varaibles. The estimates are:

$$\Delta LGDP_{i,t} = \tau_i + \sum_{\sigma=1}^{\sigma}\rho_i^{(\sigma)}\Delta LGDP_{i,t-\sigma} + \sum_{\sigma=1}^{\sigma}\pi_i^{(\sigma)}\Delta LFD_{i,t-\sigma} + \sum_{\sigma=1}^{\sigma}\mu_i^{(\sigma)}\Delta LTOP_{i,t-\sigma} + \sum_{\sigma=1}^{\sigma}\omega_i^{(\sigma)}\Delta LRE_{i,t-\sigma} + \aleph_{i,t} \quad (32)$$

$$\Delta LFD_{i,t} = \tau_i + \sum_{\sigma=1}^{\sigma}\pi_i^{(\sigma)}\Delta LFD_{i,t-\sigma} + \sum_{\sigma=1}^{\sigma}\rho_i^{(\sigma)}\Delta LGDP_{i,t-\sigma} + \sum_{\sigma=1}^{\sigma}\mu_i^{(\sigma)}\Delta LTOP_{i,t-\sigma} + \sum_{\sigma=1}^{\sigma}\omega_i^{(\sigma)}\Delta LRE_{i,t-\sigma} + \aleph_{i,t} \quad (33)$$

$$\Delta LFD_{i,t} = \tau_i + \sum_{\sigma=1}^{\sigma}\pi_i^{(\sigma)}\Delta LFD_{i,t-\sigma} + \sum_{\sigma=1}^{\sigma}\rho_i^{(\sigma)}\Delta LGDP_{i,t-\sigma} + \sum_{\sigma=1}^{\sigma}\mu_i^{(\sigma)}\Delta LTOP_{i,t-\sigma} + \sum_{\sigma=1}^{\sigma}\omega_i^{(\sigma)}\Delta LRE_{i,t-\sigma} + \aleph_{i,t} \quad (34)$$

$$\Delta LFD_{i,t} = \tau_i + \sum_{\sigma=1}^{\sigma}\pi_i^{(\sigma)}\Delta LFD_{i,t-\sigma} + \sum_{\sigma=1}^{\sigma}\rho_i^{(\sigma)}\Delta LGDP_{i,t-\sigma} + \sum_{\sigma=1}^{\sigma}\mu_i^{(\sigma)}\Delta LTOP_{i,t-\sigma} + \sum_{\sigma=1}^{\sigma}\omega_i^{(\sigma)}\Delta LRE_{i,t-\sigma} + \aleph_{i,t} \quad (35)$$

$$\Delta LTOP_{i,t} = \tau_i + \sum_{\sigma=1}^{\sigma}\mu_i^{(\sigma)}\Delta LTOP_{i,t-\sigma} + \sum_{\sigma=1}^{\sigma}\pi_i^{(\sigma)}\Delta LFD_{i,t-\sigma} + \sum_{\sigma=1}^{\sigma}\rho_i^{(\sigma)}\Delta LGDP_{i,t-\sigma} + \sum_{\sigma=1}^{\sigma}\omega_i^{(\sigma)}\Delta LRE_{i,t-\sigma} + \aleph_{i,t} \quad (36)$$

$$\Delta LRE_{i,t} = \tau_i + \sum_{\sigma=1}^{\sigma}\omega_i^{(\sigma)}\Delta LRE_{i,t-\sigma} + \sum_{\sigma=1}^{\sigma}\mu_i^{(\sigma)}\Delta LTOP_{i,t-\sigma} + \sum_{\sigma=1}^{\sigma}\pi_i^{(\sigma)}\Delta LFD_{i,t-\sigma} + \sum_{\sigma=1}^{\sigma}\rho_i^{(\sigma)}\Delta LGDP_{i,t-\sigma} + \aleph_{i,t} \quad (37)$$

4. RESULTS AND DISCUSSION

The descriptive statistics and correlation matrix presented provide useful insights into the properties of key variables and their interrelationships in the panel of D-8 countries. Starting with the descriptive statistics in Table 1, a few notable patterns emerge. Economic growth (LGDP) demonstrates substantial variation as indicated by the wide range and standard deviation of 2.79-3.3% and 0.725 respectively around a mean of 1.573 (Samadi et al., 2020). Financial development (LFD) also exhibits volatility evidenced through the large maximum, minimum, standard deviation and non-normal kurtosis. Meanwhile, renewable energy consumption (LRE) reveals more consistency between the mean of 6.414 and median of 6.508 (Shahbaz et al., 2022). Trade openness (LTOP) similarly shows lower dispersion. In Table 2, the correlation matrix points to statistically significant positive associations between economic growth and the other variables. The correlation between LGDP and LFD aligns with finance-growth nexus literature indicating productive financial sector development (Caporale et al., 2022). Links between greater trade and growth are also well-established in research (Sharif et al., 2022). Additionally, LRE, LFD and LTOP demonstrate strong intercorrelations, highlighting potential channels through which renewable energy influences broader economic performance (Shahbaz et al., 2023).

The second-generation pretests check important assumptions for panel data analysis. The significant Delta test indicates the presence of cross-sectional dependence, affirming the value of using second-generation approaches that permit interdependencies rather than assuming cross-unit independence (Samadi et al., 2020). The low variance inflation factors suggest multicollinearity is not a major concern. However, the significant Pesaran, Friedman, and Frees tests signal evidence of cross-sectional heterogeneity in the panels (Table 3). This highlights the need for estimators that can accommodate parameter differences across D-8 members (Shahbaz et al., 2023).

For determining unit root properties and stationarity, the IPS, Maddala-Wu, CIPS, and CADF tests were utilized. In Table 4, the consistently significant outcomes across all tests indicate the variables are integrated of order one I (1), affirming they are non-stationary in levels but achieve stationarity after first differencing (Paramati et al., 2022).

The results of multiple comprehensive panel cointegration tests provide strong evidence for the existence of long-run equilibrium relationships between renewable energy consumption, financial development, trade openness, and economic growth for the D-8 country sample. The Pedroni residual-based panel tests - comprising within dimension panel statistics and between-dimension group mean statistics - resoundingly reject the null of no cointegration under either homogeneous or heterogeneous alternatives (Table 5). This affirms a stable comovement between the variables in the panel (Paramati et al., 2022). Further confidence in long-run cointegration comes from the significant Kao test (Table 5). Utilizing an augmented Dickey-Fuller procedure tailored to panel data structures, Kao's test corroborates the single vector-based results detected by Pedroni's approach (Shahbaz et al., 2023). The more general cointegration testing methodology proposed by Larsson et al. (2001) indicates country-specific support for two cointegrating vectors in most D-8 members (Table 6). This suggests the presence of more complex, multi-dimensional equilibrium relationships. With Malaysia as the exception, the significant LR system test statistics imply the series are cointegrated for r = 2 vectors (Samadi et al., 2020). Finally, the robust second-generation Westerlund (2007) cointegration suite, accounting for cross-dependence and heterogeneity, further cements long-run associations between variables (Table 7). The Gt, Ga, Pt and Pa statistics strongly reject the null of no cointegration under both constant and trending specifications (Alola et al., 2021).

The panel ARDL results in Table 8 provide useful preliminary insights into the linkages between financial development, trade openness, renewable energy use and economic growth across

Table 1: Descriptive statistics

Statistical Test	LGDP	LFD	LRE	LTOP
Mean	1.573	−7.50E-09	6.414	3.793
Median	1.698	−0.085	6.508	3.724
Maximum	3.303	4.075	8.026	5.395
Minimum	−2.797	−4.226	4.463	2.198
SD	0.725	1.614	0.801	0.575
Skewness	−1.623	0.192	−0.341	0.616
Kurtosis	0.139	1.306	2.929	1.745

SD: Standard deviation

Table 2: Correlation matrix

Variables	LGDP	LFD	LRE	LTOP
LGDP	1.000			
LFD	0.105*	1.000		
	(0.034)			
LRE	−0.003	0.551*	1.000	
	(0.9543)	(0.000)		
LTOP	0.235*	0.638*	0.480*	1.000
	(0.000)	(0.000)	(0.000)	

Table 3: Second generation pre-test

Statistical Test	Delta	P-value	VIF	
adj				
	2.463**	0.014		
	2.596**	0.009		
			1.94	0.5149
			1.76	0.5692
			1.50	0.6681
Pesaran test	2.271**	0.0231		
Friedman test	72.894*	0.000		
Frees test	0.126**	0.002		

Table 4: Results of unit root test

Variables	IPS	Madalla and Wu	CIPS	CADF	Order of integration
LGDP	19.301*	334.824*	−6.420*	−7.407*	I (1)
LFD	9.300*	109.748*	−5.752*	−4.215*	I (1)
LTOP	10.161*	125.829*	−6.392*	−5.949*	I (1)
LRE	4.218*	81.918*	−5.905*	−3.234*	I (1)

IPS: Im, Pesaran, and shin, CIPS: Cross-sectionally augmented Im, Pesaran, and Shin, CADF: cross-sectionally augmented Dickey-Fuller

Table 5: First generation cointegration test

Pedroni Cointegration				
Statistical Test			Weighted	
	Statistic	Prob.	Statistic	Prob.
Panel v-Statistic	1.112	0.132	−0.944*	0.827
Panel rho-Statistic	−−8.794*	0.000	−8.902*	0.000
Panel PP-Statistic	−10.517*	0.000	−10.283*	0.000
Panel ADF-Statistic	−5.993*	0.000	−4.972*	0.000
	Statistic	Prob.		
Group rho-Statistic	−9.263*	0.000		
Group PP-Statistic	−12.973*	0.000		
Group ADF-Statistic	−6.834*	0.000		
Kao Recidual Cointegration				
ADF	3.178*	0.001		

Table 6: Larsson et al., (2001) cointegration results

Countries	r=0	P-values	r=1	P-values	r=2	P-values	r=3
Bangladesh	48.088**	0.048	15.852	0.722	6.045	0.690	0.879
Egypt	60.012**	0.002	33.607	0.017	11.820	0.165	0.072
Indonesia	55.949**	0.007	30.580	0.040	14.853	0.062	2.624
Iran	56.138*	0.006	29.188	0.058	9.528	0.318	2.858
Malaysia	46.715	0.063	29.449	0.054	14.326	0.074	4.082
Nigeria	80.597*	0.000	35.351	0.010	10.528	0.242	3.131
Pakistan	51.113**	0.023	28.007	0.079	9.971	0.283	2.785
Turkiye	53.075**	0.014	25.331	0.149	7.813	0.485	3.124
LR_NT	56.461		28.421		10.610		2.445
LR_TEST	12.079		7.6586		3.958		2.487
E (Z_k)	27.729		14.955		6.068		1.137
Var (Z_k)	45.264		24.733		10.535		2.212
N	8.000		8.000		8.000		8.000

Table 7: Westerlund ECM panel cointegration tests

Constant				Constant and Trend		
Statistics	Value	P-value	Robust P value	Value	P-value	Robust P value
G_t	−4.361*	0.000	0.000	−4.329*	0.000	0.000
G_a	−20.186*	0.000	0.000	−19.631*	0.074	0.000
P_t	−11.137*	0.000	0.000	−11.111*	0.000	0.000
P_a	−19.699*	0.000	0.000	−19.464*	0.000	0.000

Table 8: Panel ARDL

Dependent variable: $LNGDP_{it}$			
Variables	Coefficients	Standard error	P-value
Long-run estimates			
LFD_{it}	0.145* (2.989)	0.0485	0.003
$LTOP_{it}$	0.408* (3.101)	0.132	0.002
LRE_{it}	−0.517* (−3.660)	0.141	0.000
Short-run estimates			
ΔLFD_{it}	0.275 (1.743)	0.158	0.082
$\Delta LTOP_{it}$	0.449 (0.755)	0.102	0.451
ΔLRE_{it}	2.387** (2.235)	1.068	0.026
ectt-1	−0.8392* (−12.011)	0.0698	0.000
Hausman test	−2.47		
Log Likelihood	−306.2793		
Optimal lag length (1,1,1,1,1)			

ADRL: Autoregressive distributed lag

the D-8 countries over the long and short runs. Looking first at the long-run estimates, financial development (LFD) exerts a significant positive impact on GDP growth, aligning with existing research on the finance-growth nexus (Caporale et al., 2022). Specifically, a 1% increase in financial development correlates with a 0.145% rise in the long-run growth rate. Meanwhile, trade openness (LTOP) demonstrates an even larger positive association, with a 1% expansion in openness tied to a 0.408% improvement in economic performance (Sharif et al., 2022). These highlights open trade's growth dividends. However, renewable energy consumption (LRE) reveals an unexpected negative coefficient of −0.517 - a 1% rise links with a 0.517% long-run GDP loss. This contrasts typical energy-growth hypotheses but may reflect transition costs and dependencies on conventional energy (Paramati et al., 2022). The significant ectt-1 confirms long-run convergence. In the short-run, only changes in renewable usage show a substantial impact, with a positive elasticity of 2.387. This indicates short-term flexibility and growth benefits from renewable expansion - a 1% incremental increase associates with a 2.387% GDP bump (Shahbaz et al., 2023). Trade and financial changes demonstrate lesser short-run relevance. The lack of coefficient significance suggests more persistent long-run effects or omitted nonlinearities (Zaman et al., 2022).

The positive long-run connections detected between the growth rate and both financial maturity and openness align with substantial research documenting the growth dividends from developed financial systems and trade integration (Caporale et al., 2022; Sharif et al., 2022). However, the unexpectedly negative association with renewable consumption contrasts prevailing energy-economy theories. A potential explanation for this surprising outcome is that the costs and complexities entailed in transitioning energy dependence from conventional to renewable sources may initially exert countervailing pressures on economic performance (Paramati et al., 2022). Disruptions from substantially overhauling energy infrastructure could undermine growth in the long run. Yet, the opposite positive link found between short-run renewable consumption changes and GDP provides an insightful qualification. As increased margins of renewable energy are incorporated over discrete, shorter-term periods, flexibility and growth benefits seem to emerge. This suggests the growth consequences of renewable adoption may demonstrate distinct short- versus long-term asymmetric dynamics (Shahbaz et al., 2023; Zaman et al., 2022) The ectt-1 carries important information regarding the convergence towards long-run equilibrium. The coefficient on ectt-1 is statistically significant and negative, satisfying the key theoretical condition for the existence of a stable, correcting relationship running from the independent variables towards economic growth (Shahbaz et al., 2023).

Specifically, the estimate of −0.8392 suggests a fairly rapid correcting dynamic, with around 84% of the disequilibrium eliminated within 1 year. This fast pace of error correction

Resonates with existing evidence that macro financial variables often display momentum and mean-reversion in panels of developing economies (Zaman et al., 2022). Furthermore, the Hausman test result fails to reject the null hypothesis of no systematic difference between MG and PMG estimators. This affirms the validity of long-run parameter homogeneity imposed by the PMG approach as an appropriate modeling framework for the D-8 panel (Paramati et al., 2022).

The NARDL panel estimates Table 9 compelling evidence of asymmetric cointegrating relationships among the variables, addressing key limitations of the linear modeling. In the long-run, financial development (LFD) and trade openness (LTOP) reveal positive asymmetric effects on economic growth - their downside and upside shifts exert unequal impacts. Reductions in LFD and LTOP associate with disproportionately larger GDP contractions, while increase link to outsized expansions (Sharif et al., 2022; Zaman et al., 2022). This aligns with research on asymmetric business cycle effects from financial and trade fluctuations. Critically, renewable energy consumption (LREC) demonstrates significant growth penalties from negative changes but roughly symmetrical upside benefits – aligning expectations once transitionary costs are considered (Paramati et al., 2022). Hence, linearity restrictions inappropriately pooled the asymmetric dynamics. The short-run estimates also show evidence of asymmetry, particularly regarding upside LREC changes. However, the lesser short-run significance indicates adjustment lags and the primacy of long-run forces (Samadi et al., 2023).

The amplified contractions traced to financial development (LFD) and trade openness (LTOP) declines reconcile with extensive research on asymmetric business cycle effects and the generally larger magnitude of negative shocks (Sharif et al., 2022; Zaman et al., 2022). Loss of financial stability or trade access can severely disrupt productive capacity and stability. Yet renewals of financial maturity and trade may unlock outsized growth tailwinds - hence the detected upside asymmetry. Similarly, the substantial long-run growth penalties solely attached to renewable energy (LREC) reductions makes intuitive sense considering transition costs and inertia of conventional resource dependence. Backtracking renewable capacity could necessitate dramatic and efficiency-undermining system changes (Paramati et al., 2022). However, incremental renewable adoption appears to foster GDP gains more proportionally, consistent with "green growth" theories. This logic also carries through to short-run asymmetric adjustments. Upside renewable consumption changes may stimulate economic activity based on flexible capacity additions, while downshifts likely propagate more slowly as legacy systems balance suddens shocks (Samadi et al., 2023). Together, the findings clearly demonstrate the inappropriate constraints from linear specifications.

Table 9: Panel NARDL

Dependent variable: $LNGDP_{it}$			
Variables	**Coefficients**	**Standard error**	**p-value**
Long-run estimates			
LFDit+	1.236* (3.76)	0.3290	0.000
LFDit-	−1.180* (−3.70)	0.319	0.000
LTOPit+	−3.419* (−7.14)	0.479	0.000
LTOPit-	3.448* (7.63)	0.452	0.000
LREit+	−1.659 (−1.75)	0.949	0.080
LREit-	1.409* (2.88)	0.748	0.033
Symmetry test			
WFD	14.16		0.000
WTOP	55.99		0.000
WRE	3.43		0.064
Short-run estimates			
LFD_{it}^{+}	−0.507 (−1.360)	0.372	0.171
LFD_{it}^{-}	0.205 (0.830)	0.246	0.405
$\Delta LTOP_{it}^{+}$	2.208** (2.31)	0.955	0.021
$LTOP_{it}^{-}$	−0.216* (−0.54)	0.399	0.589
ΔLRE_{it}^{+}	5.875 (1.880)	3.121	0.060
ΔLRE_{it}^{-}	−0.786* (−1.430)	0.552	0.154
ect_{t-1}	−0.894* (−10.20)	0.088	0.000
Symmetry test			
W_{FD}	1.510		0.219
W_{TOP}	10.67		0.001
W_{RE}	4.16		0.041
Optimal lag length (1,1,1,1,1)			

NARDL: Non-linear autoregressive distributed lag

Table 10 presents the results of the Dumitrescu and Hurlin (2012) panel causality test, which examines both short-run and long-run causal relationships among the variables. The short-run causality is determined by the Granger non-causality test, while the long-run causality is inferred from the ectt-1.

The results indicate several significant short-run causal relationships among the variables. Financial development (LFD) Granger-causes GDP growth (LGDP), suggesting that improvements in financial development contribute to short-term economic growth. This finding is consistent with recent studies that highlight the importance of a well-functioning financial sector in facilitating investment and economic growth (Huang et al., 2021; Samargandi and Ghosh, 2020). Additionally, renewable energy consumption (LRE) Granger-causes GDP growth (LGDP), indicating that increased use of renewable energy sources can stimulate short-term economic growth. This result aligns with the findings of Adedoyin et al. (2020) and Adewuyi and Tiwari (2023), who demonstrate that renewable energy deployment can contribute to economic growth, particularly in developing economies. The results also show bidirectional causality between financial development (LFD) and renewable energy consumption (LRE), suggesting that these two variables mutually reinforce each other in the short run. This finding is supported by Koengkan et al. (2022), who argue that well-developed financial systems can facilitate investments in renewable energy projects, while the adoption of renewable energy can create new financing opportunities and stimulate financial sector growth.

The long-run causality is determined by the significance of the ectt-1. A significant negative coefficient indicates the presence

Table 10: Dumitrescu and Hurlin, (2012) results

Variables	Short-run				Long-run
	LGDP	LFD	LRE	LTOP	ect_{t-1}
LGDP	-	3.236*	10.116*	2.316**	−0.839*
LFD	2.991*	-	7.608*	1.172	−0.480
LRE	12.269*	8.140*	-	2.022	−0.078*
LTOP	2.541*	1.468	4.876*	-	−0.159*

Table 11: FMOLS granger causality results

Variables	GDP	FD	RE	TOP
LGDP	-	0.154	−0.143*	0.155*
LFD	0.114**	-	0.210*	0.133*
LRE	−0.635*	1.660*	-	0.090
LTOP	0.579*	0.843*	0.195**	-

FMOLS: Fully modified ordinary least squares

of long-run causality running from the independent variables to the dependent variable. The results show that there is long-run causality running from GDP growth (LGDP), renewable energy consumption (LRE), and trade openness (LTOP) to financial development (LFD). This finding suggests that in the long run, economic growth, increased renewable energy utilization, and greater trade openness contribute to the development of the financial sector. These results are consistent with recent studies that highlight the positive impact of economic growth, renewable energy adoption, and trade openness on financial sector development (Dong et al., 2023; Raheem et al., 2022; Vo et al., 2022). Additionally, the results indicate long-run causality running from financial development (LFD), renewable energy consumption (LRE), and trade openness (LTOP) to GDP growth (LGDP). This finding aligns with the finance-growth nexus literature, which suggests that financial development is a crucial determinant of long-term economic growth (Djeri-Wake et al., 2022; Nguyen et al., 2022). The results also support the arguments made by Bekun and Agboola (2022) and Nathaniel et al. (2022), who demonstrate that renewable energy deployment and trade openness can positively impact long-term economic growth.

Table 11 presents the results of the FMOLS Granger causality test, which examines the causal relationships among the variables while accounting for potential endogeneity and serial correlation issues. The FMOLS results largely corroborate the findings from the Dumitrescu and Hurlin (2012) panel causality test. Specifically, the results confirm the long-run causal relationships identified in Table 10, such as the bidirectional causality between financial development and GDP growth, and the positive impact of renewable energy consumption and trade openness on economic growth and financial development. Several studies have emphasized the potential synergies and trade-offs between financial development, renewable energy adoption, and economic growth (Bitar et al., 2022; Charfeddine and Kahia, 2023; Nguyen and Le, 2023). Additionally, the role of trade openness in facilitating technology transfer, knowledge spillovers, and access to international markets has been widely recognized as a potential catalyst for economic growth and sustainable development (Adeleye et al., 2022; Sohag et al., 2022).

5. CONCLUSION

The objective of this study was to investigate the asymmetric effects of financial development, renewable energy consumption, and trade openness on economic growth in the D-8 Islamic countries over the period from 1970 to 2022. The study employed a comprehensive set of panel data techniques, including panel unit root tests, cointegration analysis, asymmetric panel ARDL modeling, and Granger causality tests. The results provide compelling evidence of long-run equilibrium relationships among the variables of interest. Multiple cointegration tests, including Pedroni's residual-based panel tests, Kao's augmented Dickey-Fuller procedure, Larsson's system approach, and Westerlund's second-generation tests, consistently reject the null hypothesis of no cointegration, affirming the stable comovement between economic growth, financial development, renewable energy consumption, and trade openness in the D-8 country sample. The panel ARDL estimates reveal significant positive impacts of financial development and trade openness on long-run economic growth, aligning with existing literature on the finance-growth nexus and the growth-enhancing effects of open trade. However, renewable energy consumption exhibits an unexpected negative coefficient in the long run, potentially reflecting transition costs and dependencies on conventional energy sources. In the short run, only changes in renewable energy usage demonstrate a substantial positive impact on economic growth, indicating the immediate growth benefits of expanding renewable energy deployment. Notably, the asymmetric NARDL panel estimates uncover compelling evidence of differential impacts from positive and negative changes in the explanatory variables. Financial development and trade openness exhibit positive asymmetric effects, with downside shocks associated with disproportionately larger GDP contractions compared to upside gains. Renewable energy consumption demonstrates significant growth penalties from negative changes but roughly symmetrical upside benefits, once transitionary costs are considered. The panel causality tests further corroborate these findings, revealing significant short-run and long-run causal relationships among the variables. Financial development, renewable energy consumption, and trade openness Granger-cause economic growth in both the short and long run, while economic growth, renewable energy, and trade openness contribute to the development of the financial sector in the long run. These causal linkages are confirmed by both the Dumitrescu and Hurlin heterogeneous panel Granger causality tests and the FMOLS Granger causality estimates. This study makes significant contributions to the literature by providing empirical evidence on the interrelationships among financial development, renewable energy adoption, trade openness, and economic growth in the context of D-8 Islamic countries. The findings underscore the importance of promoting well-functioning financial systems, facilitating investments in renewable energy sources, and enhancing trade openness as potential drivers of sustainable economic growth. Future research should address limitations related to data availability, omitted variables, cross-sectional heterogeneity, and potential nonlinearities by exploring alternative data sources, incorporating additional relevant factors, conducting country-specific or regional analyses, and employing advanced nonlinear modeling techniques. Additionally, qualitative approaches and interdisciplinary collaborations could provide deeper insights into the decision-making processes, challenges, and success factors associated with leveraging financial development, renewable energy adoption, and trade openness to achieve sustainable economic growth in the D-8 Islamic countries and beyond.

5.1. Implication of the Study

Based on the study examining the asymmetric effects of renewable energy use, financial development, and trade openness on economic growth in D-8 Islamic countries, there are several managerial, theoretical, social, and practical implications. Policymakers should focus on developing robust and well-regulated financial systems, as financial development positively impacts economic growth in both the short and long run. Measures such as strengthening banking regulations, promoting capital market development, and encouraging new financial service providers can facilitate investment and resource allocation. Managers in the public and private sectors should prioritize investments in renewable energy projects to stimulate short-term and long-term economic growth. Developing supportive policies, offering financial incentives, and fostering public-private partnerships can accelerate the deployment of renewable energy technologies. Trade openness strategies should be explored by managers to enhance participation in international trade. Diversifying export markets, improving logistics and supply chain management, and leveraging free trade agreements can contribute to economic growth and financial sector development. Policymakers should consider the asymmetric effects of financial development, trade openness, and renewable energy consumption on economic growth. Downside shocks in these areas may disproportionately impact growth, necessitating targeted interventions to mitigate negative effects.

The study reinforces the finance-growth nexus theory, which posits that financial development is a crucial determinant of long-term economic growth. The findings provide empirical evidence supporting this theory in the context of D-8 Islamic countries. The research contributes to the energy-growth literature by demonstrating that renewable energy consumption can positively impact economic growth, particularly in the short run. However, the negative long-run effects observed may reflect transition costs and dependencies on conventional energy sources. The study aligns with existing literature on the role of trade openness in promoting economic growth. Greater integration into global markets facilitates technology transfer, knowledge spillovers, and access to larger consumer bases, thereby stimulating economic growth and financial sector development. The application of asymmetric panel modeling techniques contributes to understanding the differential impacts of positive and negative changes in key variables on economic growth. These addresses limitations of linear symmetric frameworks and provides insights into the complex dynamics of economic growth, financial development, and energy transitions.

The promotion of renewable energy sources can enhance energy security and contribute to sustainable development goals by reducing reliance on fossil fuels and mitigating environmental degradation. This benefits society as a whole by addressing climate change challenges and improving air quality. Investments in renewable energy projects and the expansion of international trade can create new employment opportunities and foster skills development, leading to improvements in living standards, income levels, and overall social well-being. The emphasis on renewable energy adoption can raise environmental awareness and foster a more environmentally conscious society, encouraging individuals, communities, and organizations to make sustainable choices and support policies that promote renewable energy and sustainable development. The study highlights potential investment opportunities in the renewable energy sector and industries that facilitate international trade. This information can guide investors, entrepreneurs, and businesses in identifying promising ventures and allocating resources effectively. The findings can inform the formulation of policies aimed at promoting financial sector development, renewable energy adoption, and trade openness. Policymakers can use these insights to design and implement targeted strategies and incentives to stimulate growth in these areas. The results can serve as a benchmark for evaluating the performance of countries or regions regarding financial development, renewable energy deployment, trade openness, and economic growth. This information can aid in identifying areas for improvement and implementing best practices from top-performing economies. The study underscores the need for interdisciplinary collaboration among policymakers, financial institutions, energy companies, trade organizations, and other stakeholders. Coordinated efforts across these domains can yield synergistic benefits and accelerate progress toward sustainable economic growth.

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