Journal of Environmental Management 387 (2025) 125961

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Political and financial risks in developing countries: Implications for energy security and the transition to renewable energy

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ARTICLE INFO

Keywords:
Energy security
Renewable energy adaptation
Political risk
Financial risk
Sustainable energy transition

ABSTRACT

This study investigates the impact of political and financial risks on energy security (ES) and renewable energy adoption (REA) in developing countries. Utilizing a dynamic panel data approach with the Generalized Method of Moments (GMM) estimator, we assess how these risks influence various indicators of energy security and renewable energy investment across 36 developing countries from 1990 to 2022. Our empirical findings reveal that reducing political and financial risks enhances energy security and facilitates the transition to renewable energy sources. Lower political risk creates a stable environment conducive to long-term investments in the energy sector, while reduced financial risk lowers the cost of capital, making large-scale energy projects more feasible. The interaction of these risks fosters investor confidence, attracts foreign direct investment, and promotes innovation and competition within the energy sector. Additionally, GDP growth and trade openness positively impact ES and REA by providing financial resources and enabling the exchange of advanced technologies. However, high human capital levels may increase energy consumption due to greater economic activity and higher living standards, posing challenges to energy security and the renewable transition. These insights offer valuable policy recommendations for enhancing energy security and promoting sustainable energy transitions in politically and financially volatile environments.

1. Introduction

Energy security is a paramount pillar for fostering sustainable development, encompassing various aspects such as economic, social, and environmental stability. The continuous availability, accessibility, and affordability of energy resources play a crucial role in driving economic growth, promoting social equality, and mitigating environmental harm (Tete et al., 2023; Zakari and Oluwaseyi Musibau, 2024). In today's interconnected global landscape, energy security exceeds access to conventional fossil fuels. It involves shifting towards renewable energy sources to address climate change and reduce reliance on finite resources (Iyke, 2024). Additionally, energy security is closely linked to geopolitical stability, as nations aim to protect their energy supplies amidst geopolitical tensions and changing power dynamics (Husain et al., 2024; Zhang et al., 2024). Achieving energy security requires a comprehensive approach, including strong energy infrastructure, diverse energy sources, effective governance, and strategic international partnerships. As the world grapples with sustainable development and climate change challenges, prioritizing energy security becomes increasingly urgent, highlighting the need for collaborative efforts towards a resilient, fair, and sustainable energy future.

Fig. 1 illustrates that global energy security has steadily improved over time, displaying a clear upward trend. Although developing countries have also made progress, their pace remains slower, underscoring a persistent gap between them and the global average. This indicates that while energy security is advancing worldwide, developing nations continue to face challenges in matching global progress. In contrast, Fig. 2 depicts the trend of renewable energy adoption globally and in developing countries. Both show a positive trajectory; however, developing countries demonstrate a slower rate of adoption, as reflected in the linear trends. This disparity highlights the need for targeted policies, increased financial support, and technology transfer to accelerate renewable energy adoption in these regions.

Despite the significance of these matters, there remains a shortage of empirical research that thoroughly investigates the simultaneous impact of political and financial risks on both energy security and the adoption of renewable energy in developing countries. Existing studies tend to examine these risks separately or primarily focus on other issues, thus

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https://doi.org/10.1016/j.jenvman.2025.125961
Received 6 February 2025; Received in revised form 19 May 2025; Accepted 23 May 2025
Available online 27 May 2025
0301-4797/

leaving a gap in the literature concerning the specific challenges encountered by developing nations. For example, the works of Lee et al. (2024) and Zhang et al. (2024) underscore the geopolitical risks of energy security but often lack a detailed analysis of the combined effects of political and financial risks in developing contexts. Similarly, the research conducted by Husain et al. (2024) on geopolitical risk and renewable energy and by Alsagr (2023) on financial efficiency offer valuable insights, yet they rarely address the comprehensive risk environment faced by developing countries.

This study seeks to bridge this gap by conducting an empirical analysis of the impact of political and financial risks on both energy security and the transition to renewable energy in developing nations. The interplay of political and financial risks in developing countries creates a complex landscape with significant implications for energy security and the shift towards renewable energy. Developing nations, which exhibit diverse political systems, economic vulnerabilities, and institutional challenges, are particularly vulnerable to disruptions arising from political instability, regulatory ambiguities, and fiscal limitations (Overland, 2019; Blondeel et al., 2024). These risks not only destabilize energy markets but also present formidable obstacles to the adoption of renewable energy technologies, crucial for addressing climate change and advancing sustainable development goals (Curran, 2020). Therefore, gaining insights into the dynamics of political and financial risks in developing countries is crucial for devising effective strategies to bolster energy security and facilitate the transition to renewable energy sources.

Political risks in developing countries, including governance deficits, policy volatility, and geopolitical tensions, significantly impact energy policies and investment climates (Sanderink, 2020). Weak institutions, corruption, and social unrest worsen these risks, deterring investors and undermining long-term planning (Misleh et al., 2024). Financial risks like currency fluctuations, sovereign debt concerns, and capital flight also challenge energy infrastructure development and financing (Cheng et al., 2023). Limited access to finance, underdeveloped financial markets, and fiscal vulnerabilities hinder governments' ability to fund renewable energy projects, slowing progress toward sustainable energy transitions (Bourcet, 2020; Bhattarai et al., 2022). These risks have far-reaching implications for energy security, affecting supply availability, affordability, and reliability (Blondeel et al., 2024). Energy infrastructure and supply chain vulnerabilities can cause fuel delivery disruptions, blackouts, and energy poverty, worsening socio-economic disparities and impeding development (Agbonifo, 2021; Omri and Ben Jabeur, 2024). Additionally, reliance on imported fossil fuels exposes developing countries to external shocks and geopolitical pressures, heightening energy security concerns (Lee et al., 2024). Therefore, transitioning to renewable energy becomes crucial for enhancing energy security by diversifying sources, reducing fossil fuel dependency, and increasing resilience to external shocks (Shahbaz et al., 2023; Ullah et al., 2024).

However, the shift to renewable energy in developing nations faces obstacles from political and financial risks, potentially slowing progress and deterring investment in clean energy technologies (Overland, 2019). Policy uncertainties, regulatory hurdles, and weak institutional frameworks complicate efforts to deploy renewable energy, limiting the scope and speed of transition endeavors (Blondeel et al., 2024). Furthermore, challenges such as limited access to finance, high initial expenses, and technological disparities present additional barriers, especially in financially constrained settings (Alsagr, 2023). Overcoming these obstacles requires coordinated actions to fortify governance structures, enhance policy consistency, and secure funding for renewable energy projects while also addressing underlying socio-economic disparities and environmental issues.

This study addresses the identified gap by analyzing the dynamic connection between political and financial risks, energy security, and the transition to renewable energy. In doing so, it enriches and broadens the existing literature in the following way. First, to the best of my knowledge, this study represents the first attempt to investigate the intricate dynamics of political and financial risks within developing countries and their consequent impacts on energy security and the transition to renewable energy sources. Specifically, the objectives include empirically analyzing how political instability, regulatory uncertainties, governance deficits, and financial vulnerabilities influence energy policies and investment climates. Additionally, the study aims to identify and address challenges posed by political and financial risks to energy infrastructure development in developing nations. Secondly, this study explores the impact of political and financial risks on energy

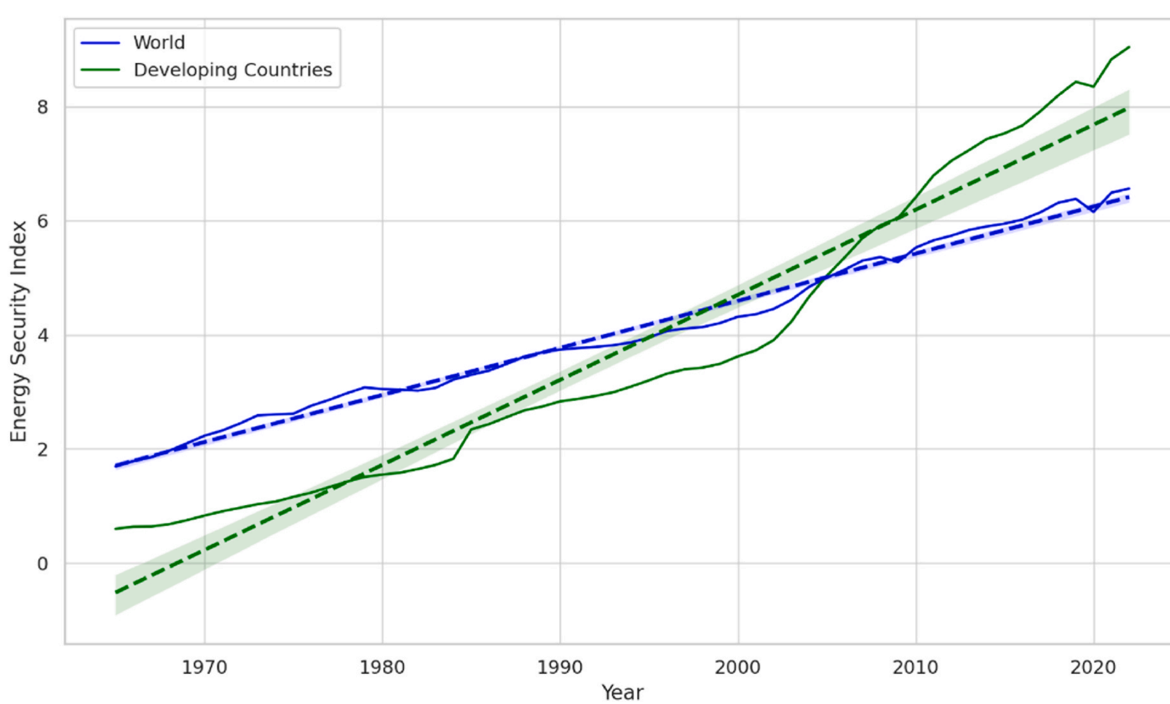

Fig. 1. Energy Security in world and developing countries over the years (Data Source: IEA).

security and renewable energy transition by incorporating interaction effects. Analyzing their interaction provides policymakers with insights into their synergistic effects, aiding in developing more effective strategies. Lastly, the investigation seeks to pinpoint strategies and policy interventions to mitigate political and financial risks, enhance energy security, and promote the transition to renewable energy, thereby contributing to the discourse on sustainable development and global energy governance.

The structure of this paper is organized as follows: the second section presents the theoretical framework and hypotheses, the third section outlines the data and methodology, the fourth section discusses the results and discussion, and the final section concludes with conclusion and policy implications.

2. Theoretical framework and hypotheses

Understanding political institutions' influence on energy policies is crucial for energy security and renewable energy transition in developing countries. These institutions shape energy development through regulatory frameworks and decision-making processes (Kern and Markard, 2016; Boța-Avram et al., 2024). Markey et al. (2022) investigated how they influence policy formulation, resource allocation, and energy project prioritization. They argue that governance structures are vital in managing political risks in energy investments. Effective mechanisms, like transparency and stakeholder engagement, promote policy stability and investor confidence. Scholars use empirical analysis to identify best practices in resilient energy governance, aiding policymakers and practitioners. For instance, Jiang and Martek (2021) underscores how political instability hampers foreign direct investment (FDI) in energy, causing delays and cancellations. Additionally, political risks worsen energy supply chain vulnerability, especially in geopolitically tense regions. Wei et al. (2023) stress that how political instability disrupts oil and gas exports, endangering energy security in fossil fuel-dependent developing nations. These challenges underscore the necessity for diversification and renewable energy adoption to mitigate geopolitical risks (Ren et al., 2024).

Moreover, political institutions determine the direction and speed of energy policy formulation and implementation, profoundly impacting energy security and sustainability outcomes (Jordan et al., 2015). Furthermore, understanding governance structures is vital for navigating political risks in developing countries (Sovacool and Dworkin, 2015). Governance mechanisms, including regulatory frameworks and transparency measures, mitigate political risks by promoting accountability and policy stability (Ashraf, 2022a). By unraveling governance intricacies, researchers provide insights into effective strategies for promoting resilient energy systems and transitioning to renewable energy in developing nations. For instance (Ullah et al., 2024), advocate a comprehensive approach to evaluating energy security, considering both internal politics and external geopolitics. Pata et al. (2023) stress how regulatory uncertainty hampers renewable energy projects, deterring investors and slowing sustainability efforts. Additionally, Michalena and Hills (2013) focuses on the role of political institutions and governance in shaping energy policies. They emphasize the need for institutional capacity-building and governance reforms to support renewable energy deployment.

Financial risk is pivotal in shaping energy security and facilitating the shift towards renewable energy sources. It encompasses uncertainties surrounding capital investment, market fluctuations, and credit availability. Exploring capital flows and investment dynamics in developing nations provides insight into the intricate nature of financial resource allocation within energy projects (Alsagr, 2023; Athari, 2024). This exploration elucidates various avenues for capital entering energy sectors, such as foreign direct investment, development aid, and domestic financing mechanisms (Rafiq et al., 2024). Alsagr and van Hemmen (2021) discovered that uncertainty in financial markets diminishes investor confidence in renewable energy projects, resulting in project delays and cancellations. Similarly, research conducted by Zhang et al. (2021) illustrates how credit limitations and fluctuations in capital markets hinder investment in renewable energy within developing nations, exacerbating vulnerabilities in energy security.

One theoretical perspective emphasizes the impact of financial markets on energy investments and infrastructure development. Financial theory posits that energy projects face various risks, including market volatility, fluctuations in interest rates, and credit limitations. These risks significantly influence investment decisions and the viability of renewable energy projects, given their reliance on substantial capital

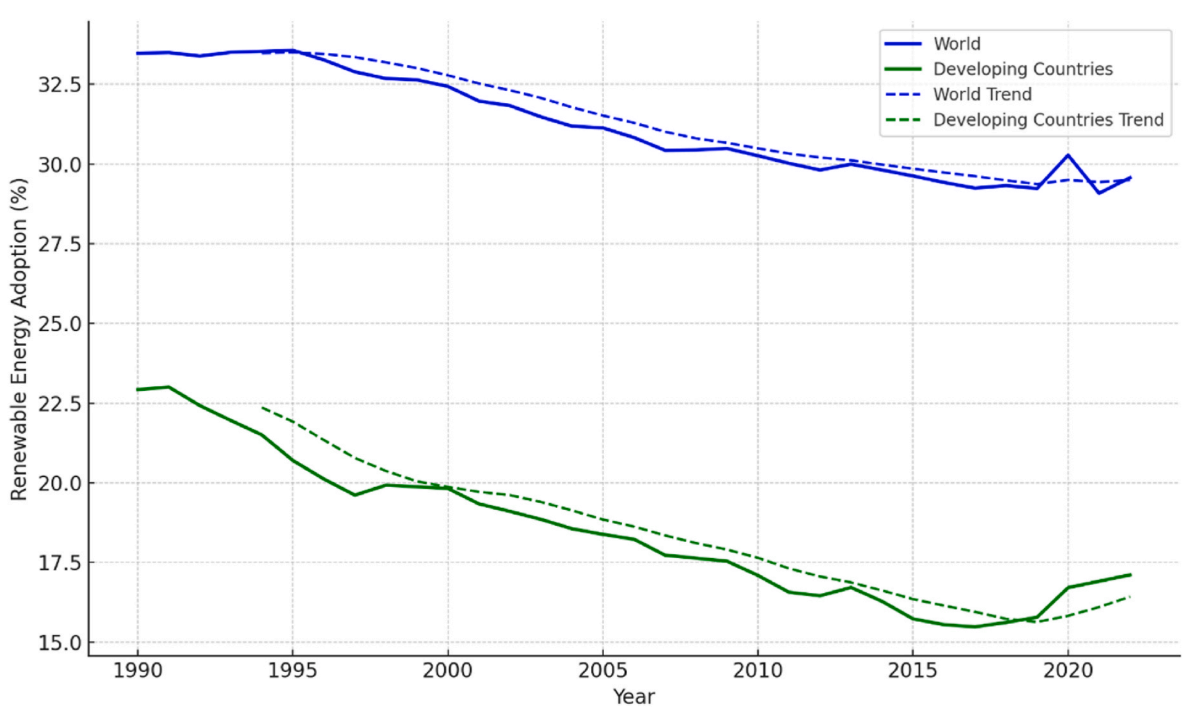

Fig. 2. Renewable Energy Adoption in world and developing countries over the Years (Data Source: World bank).

investment (He et al., 2019). Models like the Capital Asset Pricing Model (CAPM) and Real Options Theory provide insights into how financial risk factors shape energy investment strategies and project valuation. For instance, He et al. (2019) suggested utilizing green bonds and venture capital funding to stimulate private sector investments in renewable energy projects. This approach aims to broaden financing resources and lessen dependence on conventional banking channels. Qadir et al. (2021) explained how credit constraints and regulatory uncertainties hinder the financing of renewable energy, thereby sustaining reliance on conventional energy sources. These obstacles highlight the necessity for innovative financing mechanisms and policy frameworks to encourage investments in renewable energy within developing economies (Lee, 2021; Liu et al., 2023).

A vital theoretical framework for comprehending the convergence of political and financial risks in developing nations, particularly concerning energy security and the shift towards renewable energy, is the Political Economy perspective. This framework explores the intricate interconnection among political institutions, economic frameworks, and societal interests. It underscores how political choices and power dynamics influence financial investments, regulatory structures, and policy trajectories within the energy sector (Kuzemko et al., 2019). Emphasizing the importance of political stability, effective governance, and institutional capacity, it delineates how these factors can either facilitate or impede the transition to renewable energy. Furthermore, it acknowledges the impact of global market dynamics and international relations on domestic energy policies and investments in developing countries.

Moreover, the combined effect of political and financial risks on energy security and renewable energy adoption can be explained through institutional theory and resource dependence theory. Political risks, such as policy uncertainty or geopolitical tensions, create an unpredictable environment, discouraging investment in long-term energy projects (Henisz and Zelner, 2010). Financial risks, like currency fluctuations and limited access to capital, raise the cost of financing renewable energy projects (Pfeffer and Salancik, 2015). Together, these risks form a cycle where political instability exacerbates financial uncertainty, and financial constraints hinder the transition to renewables (Wüstenhagen and Menichetti, 2012). However, strong institutions, supportive policies, and financial innovations (e.g., green bonds) can mitigate these risks and promote energy security and the adoption of renewable energy (Sovacool and Geels, 2016).

Building upon the theoretical framework elucidating the intricate interplay between political and financial risks, energy security, and the transition to renewable energy in developing countries, this study posits three hypotheses. Firstly, it is anticipated that lowering financial risk improves accessibility to capital, facilitating the transition to renewable energy and enhancing energy security through reduced dependence on volatile fossil fuel markets. Secondly, it is hypothesized that reducing political risk fosters stable investment climates, incentivizing the adoption of renewable energy technologies and bolstering energy security by diversifying energy sources. Finally, it is hypothesized that decreasing the interaction between political and financial risks mitigates investment uncertainty, fostering a conducive environment for renewable energy deployment and fortifying energy security by fostering coherent energy policies and attracting diverse funding sources.

3. Data and methodology

3.1. Data description

This study utilizes panel data covering 36 developing countries spanning from 1990 to 2022, which are listed in Appendix A1. The exclusion of other developing countries is due to data unavailability. The choice of the initial year, 1990, is informed by energy security (*ES*) data, while the end year, 2022, aligns with data availability for other variables. This study's energy security index data is derived from the International Energy Agency (*IEA*) and World Development Indicators (*WDI*). These indicators are frequently regarded as crucial components of *FS* (Le and Nguyen, 2019; Lee et al., 2022) and have been employed to represent *FS* in numerous prior studies (Li et al., 2016; Le et al., 2019; Elfarra et al., 2024). Canh et al. (2021) suggest that institutional quality plays a central role in energy security and efficiency discussions by such indicators. Consequently, we use the energy security index to assess the energy status. In addition, the fundamental variables needed for calculations, such as *GDP* per capita (*GDP*), trade openness (*TO*), human capital (*HC*), political risk index (*PR*), and financial risk index (*FR*), are sourced from the *WDI*, *PWT* and *ICRG* databases. Additional information on data sources and variable descriptions is provided in the Supplementary Information section, including details in Appendix Tables *A*2 and *A*3.

Before proceeding with further analysis, we first conduct some preliminary observations. We use the variance inflation factor (*VIF*) and the correlation matrix to check for multicollinearity. According to Kennedy (2008) and Wooldridge (2020), a pairwise Pearson correlation value greater than 0.80 or a *VIF* value greater than 10 suggests significant multicollinearity. Marcoulides and Raykov (2019) also state that a *VIF* value greater than 5 indicates significant multicollinearity. Tables 1 and 2 demonstrate no strong linear correlation between the variables. Therefore, multicollinearity does not pose a concern in this study.

3.2. Model specification

To fully understand the model's variables, we must first delve into the study's conceptual framework. A conceptual framework for analyzing the interplay of political and financial risks in developing countries and their influence on energy security and the transition to renewable energy can be constructed by integrating insights from political economy and sustainable development paradigms. Political risk manifested through instability, uncertain policymaking, and governance shortcomings, coupled with financial risk, marked by restricted capital access, fluctuating exchange rates, and economic unpredictability, collectively generate an unstable setting that undermines energy security. This framework argues that heightened political and financial risks deter investment attractiveness, impede infrastructure expansion, and elevate capital costs, all pivotal factors for adopting renewable energy sources. Furthermore, institutional theory underscores the necessity of robust governance frameworks and stable financial infrastructures in facilitating this transition. Fig. 3 illustrates the interconnections between political and financial risks and their impact on energy security and the transition to renewable energy in developing countries.

Consequently, an empirical model can be devised to investigate the correlation between political and financial risk metrics and indicators of energy security and renewable energy investment while factoring in control variables such as economic development, trade openness, and human capital. GDP growth reflects the level of economic activity influencing energy demand and supply dynamics, as established in previous studies (Doytch and Narayan, 2021; Narayan and Doytch, 2017). Trade openness facilitates the flow of technology and investments across borders, thereby supporting renewable energy adoption and improving energy security (Zeren and Akkuş, 2020). Human capital represents the skills and knowledge base necessary for

Table 1
Multicollinearity among the variables (Dependent variable ES).

Variables	*ES*	*FR*	*PR*	*GDP*	*TO*	*HC*	*VIF*
ES	1.000						
FR	0.292	1.000					1.04
PR	0.038	0.130	1.000				1.36
GDP	0.037	0.113	0.394	1.000			1.19
TO	0.159	0.133	0.331	0.148	1.000		1.16
HC	−0.038	0.137	0.296	0.159	0.242	1.000	1.14

Table 2
Multicollinearity among the variables (Dependent variable REA).

Variables	*REA*	*FR*	*PR*	*GDP*	*TO*	*HC*	*VIF*
REA	1.000						
FR	0.210	1.000					1.02
PR	0.420	0.130	1.000				1.31
GDP	0.362	0.113	0.394	1.000			1.14
TO	0.389	0.133	0.331	0.148	1.000		1.15
HC	−0.441	0.137	0.296	0.159	0.242	1.000	1.14

innovation and efficient energy use, which can enhance renewable energy uptake while also potentially increasing energy consumption due to higher economic activity (Kuzmin et al., 2024). Such an approach enables the assessment of how political and financial instability directly impacts the strategic adoption of renewable energy in developing nations.

Drawing from the aforementioned theoretical framework, we develop our empirical model. By incorporating energy security (*ES*) as the dependent variable, the model can be formulated as follows:

$$ES_{it} = \beta_0 + \beta_1 ES_{it-1} + \beta_2 FR_{it} + \beta_3 PR_{it} + X_{it}\beta' + \eta_i + \varepsilon_{it} \tag{1}$$

Similarly, if renewable energy adoption (*REA*) is included as the dependent variable, the model can be expressed as follows:

$$REA_{it} = \beta_0 + \beta_1 REA_{it-1} + \beta_2 FR_{it} + \beta_3 PR_{it} + X_{it}\beta' + \eta_i + \varepsilon_{it} \tag{2}$$

We use the interaction term between political and financial risks to capture the combined effect of these risks on energy security and the transition to renewable energy. This allows us to understand how the interplay between political instability and financial constraints jointly impacts these outcomes. It helps reveal whether the risks amplify or mitigate each other's influence on the transition process.

$$ES_{it} = \beta_0 + \beta_1 ES_{it-1} + \beta_2 FR_{it} + \beta_3 PR_{it} + X_{it}\beta' + \beta_4 (PR^*FR)_{it} + \eta_i + \varepsilon_{it} \tag{3}$$

$$REA_{it} = \beta_0 + \beta_1 REA_{it-1} + \beta_2 FR_{it} + \beta_3 PR_{it} + X_{it}\beta' + \beta_4 (PR^*FR)_{it} + \eta_i + \varepsilon_{it} \tag{4}$$

Here the response factor in this model is *ES* and *REA*; denoted by β_0 as the intercept and β_1, β_2, β_3 β_4 and β' as the estimated coefficients. The control variables set, represented by X_{it}, encompasses *GDP*, trade openness and human capital. η_i accounts for the indistinct time-invariant, nation-specific influence, while ε_{it} signifies the specific error term for each observation. The t and i denote time and country, respectively.

3.3. Estimation strategy

Estimating the above equations can give rise to four significant econometric challenges. Firstly, endogeneity arises when explanatory variables like *FR* and *PR* are correlated with the error term η_i, leading to biased and inconsistent parameter estimates. Secondly, our models include past values of the dependent variables ES_{it-1} and REA_{it-1} as regressors; this creates a specific endogeneity problem called dynamic endogeneity. Third, unobserved time-invariant country-specific characteristics, such as anthropology and geography, could associated with the explanatory factors and are captured in the error term η_i. Panel data

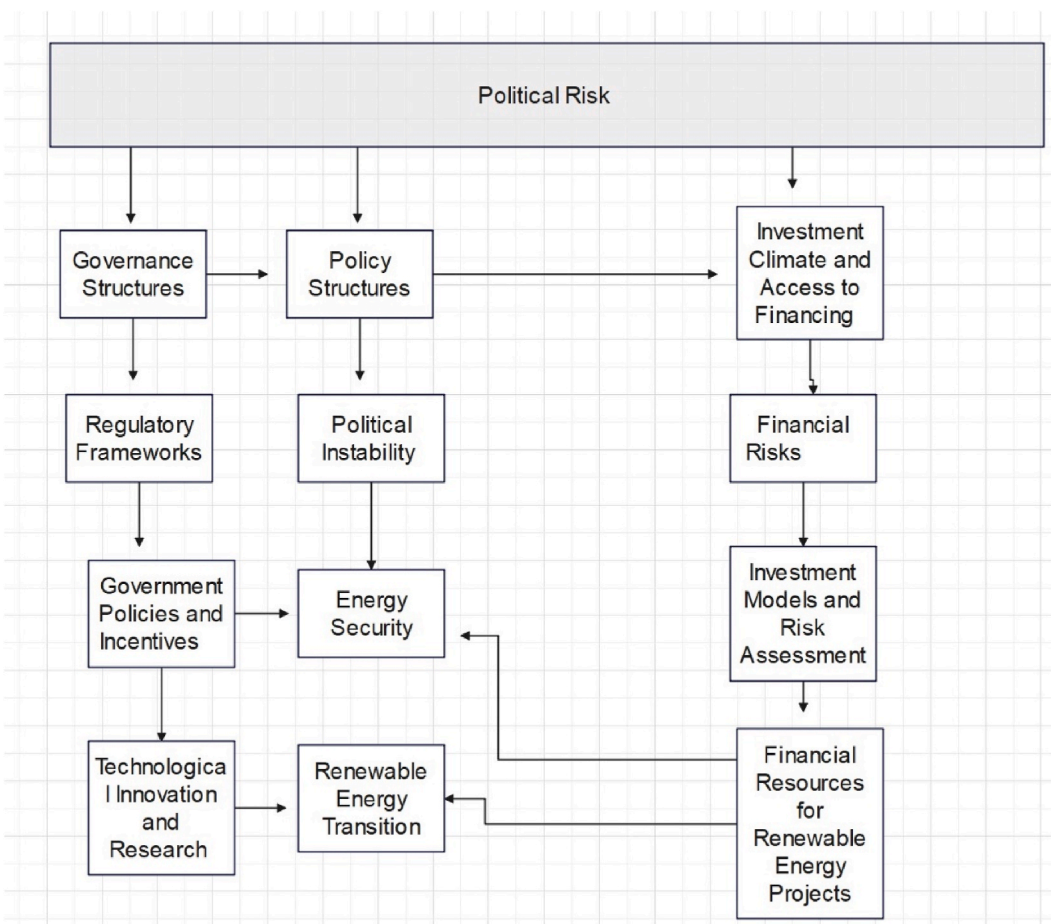

Fig. 3. Theoretical framework illustrating the impact of political and financial risks on energy security and the transition to renewable energy in developing countries.

often exhibits heteroskedasticity (variance of errors differs across entities) and autocorrelation (errors are correlated over time); traditional methods like fixed effects or random effects may not perform well. Moreover, the IV-2SLS estimator requires suitable instrumental variables beyond those included in the model. Consequently, we opt for the two-step System Generalized Method of Moments (*SGMM*) estimation method recommended by Judson and Owen (1999), supplemented by the *PMG* estimator for robustness checks (Ashraf, 2022b).

3.3.1. Generalized method of moments

The two-step *SGMM* is a method for estimating dynamic panel data models, improving upon traditional methods by addressing issues like endogeneity, autocorrelation, and heteroskedasticity (Arellano and Bover, 1995). The process involves two main equations for estimation:

i. First Difference Equation:

The first step involves transforming the original model into first differences to eliminate unobserved individual-specific effects (Judson and Owen, 1999). The differenced model is:

$$\Delta Y_{it} = \beta \Delta Y_{i(t-1)} + \Delta X_{it}\gamma + \Delta \epsilon_{it} \tag{5a}$$

where $\Delta Y_{it} = Y_{it} - Y_{i(t-1)}$ and $\Delta X_{it} = X_{it} - X_{i(t-1)}$. Internal instruments, typically lagged levels of the endogenous variables, are used for this differenced equation. Initial parameter estimates and residuals are obtained from this model.

ii. Combined Level and Difference Equations:

Using the residuals from the first step, the variance-covariance matrix of the moment conditions is constructed to re-estimate the model, combining the original level equation and the differenced equation:

$$Y_{it} = \beta Y_{i(t-1)} + X_{it}\gamma + \eta_{it} + \epsilon_{it} \tag{6}$$

$$\Delta Y_{it} = \beta \Delta Y_{i(t-1)} + \Delta X_{it}\gamma + \Delta \epsilon_{it} \tag{5}$$

In these models, Y represents the dependent variables , X represents the explanatory variables, and β and γ denote the estimated coefficients. This system includes both the level and differenced equations, employing suitable instruments to handle endogeneity. The efficient weight matrix derived from the initial residuals is applied, enhancing the efficiency of the parameter estimates.

By iterating through these steps, two-step $S-GMM$ produces consistent and efficient estimates for dynamic panel data models, effectively addressing various econometric issues inherent in panel data analysis (Roodman, 2009).

The Hansen and Arellano-Bond statistics are essential for validating the model and ensuring the robustness of *GMM* results. The Hansen test checks the validity of the instruments in the model; a high p-value (typically above 0.05) suggests that the instruments are valid and the model is correctly specified. The Arellano-Bond statistic assesses serial correlation in the residuals of the differenced equation in *GMM* estimation. Ensuring the absence of $AR(2)$ serial correlation is crucial for the validity of the instruments. These tests confirm that the *GMM* estimations are reliable and that the instruments used are appropriate, providing confidence in the model's results.

3.3.2. Pooled Mean Group (PMG) estimator

The *PMG* estimator, devised by Pesaran et al. (1999), is employed to validate the robustness of $S-GMM$ estimates. The PMG estimator is often applied within an Error Correction Model (ECM) framework, which captures short-run adjustments and long-run equilibrium relationships. The model can be represented as:

$$\Delta Y_{it} = \varnothing S_{it-1} + \sum_{j=1}^{p} \delta_{ij}\Delta X_{it-j} + \eta_{it} + \xi_{it} \text{ where } S_{it-1} = Y_{it-1} - \theta X_{it-1} \tag{7}$$

In this model, Y represents the dependent variables ; S_{it-1} signifies the deviation from *LR* equilibrium at any given period for group i, and φ represents the error-correction coefficient, also known as the speed of adjustment. The vector φ encapsulates the *LR* coefficients, which remain consistent across groups and denote the *LR* elasticity of *ESR* concerning each factor in X_{it-1}. The vector δ delineates the *SR* responses of the X factors, while η_i and ε_{it} interpret as like equation 1. The validity of *PMG* estimates hinges on the level and significance of the error-correction coefficient φ, which should be negative and smaller than 1.

4. Results and discussion

4.1. System GMM results

Table 3 presents the results of two-step Arellano–Bover/Blundell–Bond GMM estimations. A key requirement for system *GMM* is the absence of significant second-order autocorrelation ($AR(2)$), indicating that the estimators are not sensitive to serial correlations of this order. In this study, the Hansen test is insignificant, indicating that the instruments are not correlated with the residuals and are valid. The energy security (*ES*) and renewable energy adaptation (*REA*) lag terms are positive, and it suggests that improvements in energy security and the adoption of renewable energy sources in the past positively influence current outcomes. This indicates a beneficial lag effect where past investments and policies continue to yield positive results over time.

The financial risk (*FR*) coefficient positively affects *ES* and *REA*, suggesting that lowering *FR* in a country enhances both *ES* and *REA*, thereby supporting Hypothesis 1. In addition, *FR* still positively impacts *ES* and *REA* when we put in control variables. The positive coefficient of *FR* on *ES* and *REA* suggests that decreasing financial risk enhances a country's energy security and its transition to renewable energy. This relationship can be understood through several mechanisms. Lower *FR* typically indicates a stable economic environment, which encourages investment in energy infrastructure and renewable energy projects (Athari, 2024). He et al. (2019) argue that reduced financial risk lowers the cost of capital, making it more feasible for both public and private sectors to finance long-term energy initiatives. Additionally, a low-risk financial environment boosts investor confidence, attracting more foreign direct investment (*FDI*) into the energy sector. This influx of investment not only improves the reliability and resilience of energy systems but also accelerates the adoption of renewable technologies by reducing uncertainties associated with large-scale, capital-intensive renewable energy projects (Qadir et al., 2021; Cheng et al., 2023). Consequently, lowering financial risk can create a positive feedback loop where improved energy security and increased renewable energy adoption reinforce each other, fostering sustainable and resilient energy systems.

The political risk (*PR*) coefficient positively affects *ES* and *REA*, suggesting that lowering *PR* in a country enhances both *ES* and *REA*, thereby supporting Hypothesis 2. In addition, *PR* still positively impacts *ES* and *REA* when we put in control variables. This relationship might be due to the fact that lower political risk reduces uncertainties for investors and businesses, creating a more favorable environment for economic activities and long-term investments (Ashraf, 2022d, 2022c), including those in the renewable energy sector. Consequently, policies aimed at reducing political risk—such as strengthening governance, ensuring the rule of law, and improving political transparency—can foster economic growth and facilitate the transition to sustainable energy systems (Ashraf et al., 2023; Wang et al., 2024). By highlighting these dynamics, the sentence underscores the importance of political stability in driving economic and environmental outcomes. Lower political risk can also lead to more consistent and supportive government

Table 3
Regression analysis.

variables	Dependent variable: *ES*			Dependent variable: *REA*		
	1	2	3	1	2	3
ES(-1)/REA(-1)	0.864* (38.31)	0.902* (70.03)	0.896* (54.95)	0.898* (108.76)	0.898* (26.15)	0.889* (50.53)
FR	0.034* (3.67)	0.019* (3.50)	0.148* (4.65)	0.127* (8.72)	0.032* (5.49)	0.245* (2.81)
PR	0.010** (2.01)	0.016* (3.45)	0.122* (3.43)	0.309* (7.8)	0.076* (3.30)	0.406* (3.32)
GDP		0.054* (4.19)	0.022** (2.12)		0.109* (3.74)	0.074* (2.78)
TO		0.096* (4.86)	0.106* (3.59)		0.129* (2.58)	0.111** (2.47)
HC		−0.060* (−3.36)	−0.066* (−2.77)		−0.158* (−6.44)	−0.021 (−0.47)
FR*PR			0.021** (2.75)			0.251* (2.98)
_cons	−0.181* (−3.60)	−0.889* (−7.26)	−1.328* (−4.44)	3.975* (10.65)	−0.380* (−4.01)	−1.852* (−2.93)
Model criteria						
Hansen test	1.01 (p = 0.316)	0.12 (p = 0.728)	1.92 (p = 0.383)	1.85 (p = 0.174)	0.73 (p = 0.393)	0.43 (p = 0.511)
***AR*(1)** test	−3.52* (p = 0.000)	−3.47 (p = 0.001)	−3.56* (p = 0.000)	−3.42* (p = 0.001)	−1.98** (p = 0.047)	−1.96** (p = 0.050)
***AR*(2)** test	−1.29 (p = 0.199)	−0.09 (p = 0.931)	−0.11 (p = 0.910)	−2.36 (0.118)	−1.87 (p = 0.162)	−1.80 (0.171)
No. of instruments	33	31	34	32	32	32
No. of groups	36	36	36	36	36	36

Note.
Source: Author's calculation. The model is estimated using the two-step model with robust estimation. The z-values in (). Asterisks *,**,and*** denote the 1%,5%, and10% levels of significance, respectively. The values of the Hansen and AR tests stand for the statistic value.

policies for renewable energy, facilitating faster and more efficient implementation of renewable projects. Reducing political risk creates a positive feedback loop where enhanced energy security and increased renewable energy adaptation mutually reinforce each other, promoting sustainable and resilient energy systems.

The control variables *GDP* and trade openness positively affect *ES* and *REA*. These findings align with the previous results reported by Lee et al. (2022) and Zeren and Akkuş (2020). The positive impacts of *GDP* and trade openness on *ES* and *REA* stem from various factors. A higher *GDP* generally signifies a stronger economy with more financial resources to invest in energy infrastructure and renewable technologies (Chang et al., 2009). Economic growth enables the adoption of cleaner energy solutions through increased spending by both the government and private sector on research and development, subsidies, and incentives for renewable energy projects. Furthermore, trade openness enhances *ES* and *REA* by facilitating the exchange of advanced technologies and best practices internationally. Open trade policies attract *FDI* into the energy sector, fostering innovation and competition, which improve efficiency and lower costs. Additionally, trade openness diversifies energy sources by allowing countries to import renewable energy technologies and components, thus reducing reliance on domestic fossil fuels and enhancing energy resilience (Ibrahiem and Hanafy, 2021). Consequently, *GDP* growth and trade openness create a favorable environment for improving energy security and accelerating the shift to renewable energy.

Another important aspect of energy security, especially in the context of developing countries, is the degree of dependence on imported energy sources. Many countries in the sample rely heavily on energy imports, which exposes them to external shocks and global price fluctuations. The positive effects of political and financial stability on energy security observed in this study may be partially attributed to the encouragement of domestic energy investments and reduced dependence on imports. A stable and transparent institutional framework can help diversify energy sources and enhance resilience through increased adoption of indigenous renewable energy technologies.

Likewise, human capital (*HC*) negatively impacts *ES* and *REA*. These findings align with the previous results reported by (Lee et al., 2022). He and Reiner (2016) argue that high levels of *HC* may result in higher energy consumption due to increased economic activity and improved living standards, potentially straining existing energy resources and infrastructure. This surge in demand can heighten energy security risks by introducing vulnerabilities within the energy supply chain. Furthermore, well-educated populations might favor more energy-intensive technologies and services, further boosting energy consumption and complicating the shift to renewable energy sources.

Moreover, the positive effect of the interaction term (*PR**FR*) on *ES* and *REA* indicates that lowering political and financial risks within a country improves its energy security and transition to renewable energy sources. This finding supports Hypothesis 3. Reduced *PR* fosters a stable environment for long-term investments, drawing domestic and foreign investors to the energy sector (Wang et al., 2024). When combined with lower *FR*, this further reduces capital costs and mitigates uncertainties, making large-scale energy projects, including renewable ones, more viable. This dual reduction in risk creates a climate of confidence and predictability, promoting sustained investment in energy infrastructure and innovation. As a result, this environment not only ensures a reliable and resilient energy supply but also speeds up the adoption of renewable energy technologies, supporting sustainable energy security and environmental goals. Therefore, reducing political and financial risks is essential for enhancing energy security and advancing renewable energy adaptation.

4.2. Robustness check

To assess the robustness of the *SGMM* estimates, we employ the Pooled Mean Group (*PMG*) method for estimating equations (1)–(4). The *PMG* estimator, which is based on an Error Correction Model (*ECM*), requires the variables to be integrated. Therefore, the first step in our analysis was to test for cross-sectional dependency, and the results presented in Table 4 indicate that cross-sectional dependency is significant. Based on this, we proceeded to apply the unit root test. To ensure appropriate co-integration among the panel variables, we tested the stationarity of the model's variables. The results from the *ADF* and *PP* tests reveal that the variables exhibit the same integration order. Given the significance of cross-sectional dependency, we further applied second-generation unit root tests—*CADF* and *CIPS*. As shown in Table 5, the variables are stationary at level $I(1)$.

Subsequently, we apply the co-integration test developed by

Table 4
Cross-sectional dependency test results.

Variables	Breusch-Pagan LM	Pesaran CD
ES	13390.82*	73.04*
REA	6351.345*	16.58*
FR	4458.04*	41.52*
PR	5752.38*	59.93*
GDP	12899.92*	102.89*
TO	4476.94*	32.45*
HC	4211.38*	13.26*

Notes: * significant at 1 % level.

Westerlund (2007). The results in Table 6 indicate that the group mean tests (*Gt* and *Ga*) support the alternative hypothesis, suggesting that the variables are cointegrated with the dependent variable. Conversely, for the *Pt* and *Pa* tests, the null hypothesis is rejected at the 1% significance level, confirming co-integration for the panel as a whole.

Table 7 outlines the *PMG* estimation results for all models. The findings from the *SGMM* analysis indicate that political and financial stability enhances economic energy security and advances renewable energy adaptation within the group of developing nations. Additionally, interaction variables positively influence energy security and renewable energy adaptation. The reliability of the *PMG* estimates is further underscored by the level and significance of the error correction coefficients.

Table 6
Westerlund cointegration test results.

Normalized variable : *ES*				
Covariates	G_t	G_a	P_t	P_a
Model 1	−2.989**	−3.527*	−4.325*	−2.059**
Model 2	−2.281**	−4.422*	−6.137*	−3.224*
Model 3	−2.903**	−4.447*	−5.659*	−3.127*
Normalized variable : *REA*				
Model 4	−2.223**	−4.241*	−3.338*	−2.685*
Model 5	−2.728*	−3.150*	−5.247*	−2.664*
Model 6	−2.284**	−4.448*	−5.809*	−2.478**

Footnote: * and ** indicate significance at the 1% and 5% level. Models 1 and 4 are baseline models. Models 2 and 5 include control variables, and Models 3 and 6 incorporate an interaction term.

5. Conclusion and policy implications

Our study provides a thorough analysis of the effects of political and financial risks on *ES* and *REA* in developing countries. By employing a dynamic panel data approach using the *GMM* estimator, we examined the interactions between these risks and various indicators of energy security and renewable energy investment. Our findings indicate that reducing political and financial risks enhances both energy security and the transition to renewable energy. Specifically, lower political risk creates a stable environment for long-term investments, attracting both domestic and foreign investors to the energy sector. This stability, combined with reduced financial risk, lowers the cost of capital and mitigates uncertainties, making large-scale energy projects more feasible. This dual reduction in risk fosters investor confidence and encourages sustained investment in energy infrastructure and innovation. Consequently, such an environment not only ensures a reliable and resilient energy supply but also accelerates the adoption of renewable energy technologies, contributing to sustainable energy security and environmental goals.

Based on our findings, several policy recommendations emerge for developing countries aiming to enhance their energy security and transition to renewable energy:

First, governments should focus on policies that improve political stability and reduce regulatory uncertainty. This includes implementing transparent and consistent energy policies that can attract long-term investments. Second, policymakers should aim to minimize financial risks by stabilizing exchange rates and interest rates and improving access to capital markets. This can be achieved through sound macroeconomic policies and financial sector reforms. Third, developing countries should create favorable conditions for both domestic and *FDI* in the energy sector. This can be done by providing financial incentives such as tax breaks and subsidies for renewable energy projects. Fourth, strengthening institutional frameworks to combat corruption and enhance regulatory quality is crucial. This will not only reduce political risk but also foster a more conducive environment for energy investments. Fifth, encouraging trade openness can facilitate the exchange of advanced technologies and best practices across borders, fostering innovation and competition in the energy sector. Policies that promote international trade in energy technologies should be pursued. Last, investments in education and training programs related to energy management and renewable technologies can build a knowledgeable workforce essential for the transition to a sustainable energy future.

By implementing these policies, developing countries can mitigate political and financial risks, thereby enhancing their energy security and accelerating the adoption of renewable energy. This dual approach not only supports economic growth and stability but also contributes to environmental sustainability and resilience.

This study has some limitations that pave the way for future research. While it touches on political risks, more detailed investigations are needed to explore specific aspects of political stability that influence energy sector investments, such as government transparency, rule of law, and policy consistency. Future research should also focus on the intersection of energy security, financial development, and climate-related risks, examining how financial markets and institutions can better adapt to the increasing challenges posed by climate change—including extreme weather events—and how this adaptation impacts energy infrastructure resilience and investment flows. Moreover, future studies could enrich the analysis by incorporating energy import dependency data to better capture the external dimensions of energy security, particularly in resource-scarce developing countries.

CRediT authorship contribution statement

Aiman Javed: Writing – review & editing, Writing – original draft. **Junaid Ashraf:** Writing – review & editing, Writing – original draft. **Li Yong:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Table 5
Unit root test results.

Variables	*ADF test − statistics*		*PP test − statistics*		CADF	CIPS	Decision
	Without trend	With trend	Without trend	With trend			
ES	228.660*	168.226*	625.620*	984.246*	−3.558*	−4.693*	*I* (1)
REA	214.038*	187.102*	547.967*	563.342*	−3.697*	−3.116*	*I* (1)
FR	274.113*	211.865*	900.443*	1939.50*	−4.398*	−5.138*	*I* (1)
PR	261.906*	161.381*	564.928*	736.941*	−4.285*	−5.588*	*I* (1)
GDP	148.427*	105.484*	453.122*	671.740*	−4.684*	−5.436*	*I* (1)
TO	283.358*	204.942*	686.783*	1038.23*	−3.918*	−4.713*	*I* (1)
HC	147.711*	109.680*	461.469*	360.196*	−3.992*	−4.157*	*I* (1)

Notes: * significant at 1 % level.

Table 7
PMG estimates: robustness analysis.

Variables	Dependent variable: *ES*			Dependent variable: *REA*		
	1	2	3	1	2	3
FR	0.200* (4.14)	0.425* (6.45)	0.519* (4.93)	0.313* (2.43)	0.326* (2.681)	1.449* (8.47)
PR	0.135** (1.95)	0.219** (2.91)	0.331** (2.57)	0.399* (2.97)	0.591** (2.462)	3.012* (8.93)
GDP		0.140*** (1.487)	0.289*** (1.83)		0.291** (1.09)	0.847* (5.14)
TO		1.067* (4.55)	1.116* (4.79)		0.321** (2.12)	0.656* (2.90)
HC		−0.793* (−5.70)	−0.867* (−5.89)		−1.498* (−3.430)	−0.947* (−2.60)
FR*PR			0.390** (2.26)			0.339* (8.814)
ECT	−0.169* (−5.19)	−0.228* (−2.03)	−0.276* (−3.83)	−0.016* (−2.71)	−0.344* (−4.91)	−0.156* (−2.95)

Notes: * significant at 1 % level, ** significant at 5 % level.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2025.125961.

Data availability

Data will be made available on request.

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