



## Research article

# Unveiling the impact of geopolitical risk, climate policy uncertainty, environmental policy stringency, and financial efficiency on renewable energy investment in the USA: Evidence from novel dynamic simulated ARDL approach

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## ABSTRACT

Fossil fuel energy consumption not only leads to climate change but also contributes to energy poverty and the unequal distribution of its supply, urging investment in alternative and clean energy sources. Furthermore, unprecedented geopolitical risk and climate policy uncertainty pose serious concerns for a steady energy supply, and the literature provides insufficient evidence for these important indicators, particularly considering the amount of renewable energy investment in the USA. The current paper formulates an interesting framework to scrutinize the impact of geopolitical risk, climate policy uncertainty, environmental policy stringency, and financial institutions' efficiency on renewable energy investment in the USA. For empirical analysis, this study utilizes modern econometric approaches such as the recently developed novel dynamic simulated ARDL and the frequency domain causality approach, harnessing the annual time series data spanning from 1990 to 2022. The obtained results explain that geopolitical risk negatively affects renewable energy investment, suggesting that higher geopolitical risk hinders renewable energy investment. Contrary to this, climate policy uncertainty, environmental policy, financial integration, and financial institutions' efficiency have a significant positive impact on renewable energy investment. In addition, the frequency domain causality test provides evidence of long, medium, and short-term causal connections between variables. The robustness analysis corroborates the main findings. Based on these results, the USA should promote renewable energy initiatives to mitigate geopolitical concerns among investors. Furthermore, the financial framework should support sustainability by directing energy investments in the capital market, encouraging long-term financial funding for energy projects, and incentivizing renewable energy investments.

## 1. Introduction

The extensive extraction of fossil fuels has not only caused severe environmental damage but also led to several economic shocks, energy poverty, geopolitical concerns, and climate change (Zhou et al., 2023). Investments in renewables enhance energy security, protect biodiversity, reduce environmental degradation, and safeguard the planet for future generations (Zhou et al., 2023). Investing in renewable energy sources is essential for sustainable development, as it signifies key

indicators of sustainability and aligns with the Sustainable Development Goals. SDG 7 specifically addresses the provision of clean energy, which consequently impacts other sustainability goals, such as SDG 13, since clean energy underpins climate action, and SDG 14 and 15, as it promotes ecological sustainability (Liu et al., 2023). Furthermore, clean and accessible energy sources are strategic commodities that ensure sovereign stability and are vital for sustainable economic growth, influencing the well-being of populations at large.

However, the proportion of renewable energy to total energy

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consumption remains relatively low. Over the next five years (2022–2027), global renewable energy capacity is projected to grow by 2400 GW, mainly driven by energy security concerns (stemming from the Russia-Ukraine war) and energy crises (IEA, 2022a). Another report by the World Bank on SDG 7 indicates that the current pace of progress towards 2030 agenda is insufficient, requiring substantial investment in renewables, diligent policy development and enforcement, as well as sovereign commitment (IEA, 2022b; World Bank, 2022). It is also important to note that the high costs associated with renewable energy generation and deployment hinder its widespread adoption compared to traditional methods. Therefore, authentic policy promotion and systemic engagement are essential to incentivize investment in renewable energy (Zhou et al., 2023). As a strategic commodity, energy investment is influenced by numerous national and international factors, including climate policy uncertainty (CPU), geopolitical risk (GPR), environmental policy (EP), financial integration (FI), and the efficiency of financial institutions (FIE). Furthermore, to formulate sustainable energy policies, policymakers require rigorous empirical evidence, and this paper contributes effectively to supporting that aim.

CPU refers to the unpredictability or ambiguity about the measures being taken by the governing body to control climate change. It rises when there is a lack of clear trajectory or policies regarding the implementation of climate-related initiatives and plans by governmental organizations at various regional, national, and international levels (Sarker et al., 2023). Due to this uncertainty concerning the policy framework, government regulations, and environmental markets, they hinder the development of renewable energy technologies and sustainable practices, as well as disincentivize business and individual investors from making renewable energy investments. Furthermore, the CPU spikes when a new major climate-related event occurs, such as presidential statements, new accords, or emission legislation to combat. Climate policy changes after the establishment of the Kyoto Protocol, Paris Agreement, Sustainable Development Goals, and COP26-27, and requires new policy frameworks to meet the targets set in these significant events. Therefore, modifications in strategies to achieve future climate visions and targets influence the consumption of renewables, fossil fuels, and investment in green energy sources (Li et al., 2023).

Another important factor influencing the dynamics of renewable energy investment is geopolitical risk. The primary cause of sharp fluctuations in crude oil prices is geopolitical turmoil in oil-producing countries, impacting demand and supply (Yang et al., 2021). Geopolitical influence, political instability, military and nuclear tensions, invasions, and wars in resource-rich nations all contribute to geopolitical risk. Additionally, competition over energy sources, manipulation of energy supply, disruption of energy infrastructure, and trade sanctions against oil-producing countries can cause fluctuations in crude oil prices, disrupt energy supplies, and affect renewable energy investment (Khan et al., 2023; Sarker et al., 2023). According to the report, Russia's invasion of Ukraine in 2022 marked a turning point for energy security and became a new incentive for renewable investment (IEA, 2022a). It has significantly impacted energy markets and green stocks while doubling household energy costs, raising concerns about geopolitical risk (Iyke, 2024).

GPR increases the costs of renewables, intensifies government and institutional investments, and may crowd out private investment, leading to increased reliance on oil and gas. However, in the long term, GPR prompts countries to develop their energy resources, particularly renewables, to ensure uninterrupted energy supply (Bashir et al., 2023), as renewable energy investment offers hedging properties and can serve as a refuge against GPR and economic policy uncertainty (Zhao et al., 2023). Nonetheless, the limited literature on the relationship between GPR and REI is confusing. Some authors argue that it hampers investment in clean energy, while others believe it supports mechanisms that encourage such investment, prompting further investigation.

Consequently, it is crucial to develop environmental policies to reduce the CPU and GPR. Environmental policy stringency (EP) has

become central to REI. According to the renewable energy report by the International Energy Agency, the expansion of renewable energy from 2022 to 2027 needs to increase by 60 %; however, in accelerated scenarios, proper and timely implementation of renewable plans and policies can close the gap in renewable energy expansion to meet the NetZero agenda (IEA, 2022a). The main goal of environmental policies is to establish and enact plans and procedures to limit environmental degradation and REI (Bashir et al., 2023). They facilitate the execution of strategies related to resource efficiency, conservation, renewable energy transition, and investment (Li and Shao, 2023; Ullah et al., 2023). However, environmental managers should differentiate between positive and negative shocks in environmental policies, as these have varying effects on renewable energy investment (Alsagr, 2023b).

In addition to these factors, renewable energy investment depends heavily on financial stability and efficiency. These projects are capital-intensive and require robust financial streams, which are only achievable with strong financial integration (Alsagr, 2023a). Sustainable development necessitates sustainable investments in R&D and renewable energy technologies; however, all of these rely on the foundation of financial integration and its efficiency. The development and integration of financial markets support the growth of the renewable energy sector (Li and Shao, 2023). Nevertheless, some studies have found that financial globalization can impede the energy transition (Ramzan et al., 2023). Therefore, the link between financial efficiency and renewable energy investment remains in its early stages, and the limited literature offers only a vague understanding of this crucial issue.

Considering the discussion above, we explore how renewable energy investment is influenced by geopolitical risk, climate policy uncertainty, environmental policy strictness, and financial integration and efficiency. We chose to gather empirical evidence from the USA economy for several reasons. First, environmentally, the USA emitted 4.7 billion metric tons of CO<sub>2</sub> in 2020, making it the world's second-largest emitter, with per capita CO<sub>2</sub> emissions higher than the global average. To meet the 2030 agenda goals, the US is committed to reducing half of its emissions, which requires investments in clean energy (Liu et al., 2023). Second, the USA's energy consumption accounted for 17 % of global primary energy use, supporting households, industry, and transportation (IEA, 2023). The USA produces 18 % of the world's oil and ranks as the top oil-producing country (Sweidan, 2021). Most significantly, the political, economic, and military interests of the US influence its global relations, making it highly susceptible to GPR and CPU. Nevertheless, according to the IEA Renewables Energy Report, the US has doubled its renewable energy capacity over the next five years, contributing to two-thirds of global energy growth. However, this progress also hinges on policy strictness and sufficient financial integration (IEA, 2022a).

This study adds novelty to the literature in several ways: first, the authors employ the novel indices for GPR, CPU, EP, FI, and FIE while controlling for oil prices and economic growth to establish the trajectory for renewable energy investment within a framework that has not been previously tested. Second, the study utilizes renewable energy investment in US dollars, which is quite a novel approach in renewable energy literature. Previously, many studies have used the concept of renewable energy investment, but have quantified it through renewable energy production and consumption. No studies in this domain have quantified investment in dollar terms. The authors believe that quantifying investment in dollar terms provides clearer insight into real-time changes. Furthermore, the authors have chosen the USA as the sample for this study because it has been involved in numerous geopolitical conflicts, has one of the largest economies, is a significant consumer of fossil fuel energy, and makes an immense contribution to environmental degradation. Literature on the USA offers evidence of these predictors for various criterion variables, e.g., carbon emission (Liu et al., 2023), volatility and returns of clean energy prices in the USA (Sarker et al., 2023), and renewable energy consumption (Sweidan, 2021; Zhang et al., 2023). Consequently, there is limited literature on the USA renewable

energy investment. However, effective policy instruments are required to address worsening climate challenges and support sustainable economic growth. Additionally, the study employs numerous econometric techniques to establish a solid empirical foundation, including the innovative dynamic ARDL (DYARDL) simulation and spectral causality approach, alongside other diagnostic tests. These models yield robust findings and offer theoretical justification for analyzing time series data, enabling the formulation of comprehensive policies. Overall, this paper highlights that geopolitical risk can hinder renewable energy investment. At the same time, climate policy uncertainty, environmental policy stringency, financial institutions' efficiency, financial integration, oil prices, and GDP tend to promote investment in the renewable energy sector.

The remaining part of the research is organized as follows: Section 2 provides a brief overview of previous studies. Section 3 explains the theoretical framework of the study. Section 4 details the data, variables, and the methodology used. Section 5 discusses the results and their interpretation. Finally, Section 6 offers the conclusion and policy recommendations.

## 2. Literature review

### 2.1. Geopolitical risk and renewable energy investment

Geopolitical risk stems from unstable governments, invasions, and wars, primarily in oil-producing nations. It is a key factor behind sharp fluctuations in crude oil prices, which also encourages stable renewable energy deployment and consumption (Yang et al., 2021). Additionally, other geopolitical events such as 9/11, the Russia-Ukraine conflict, the escalation of Islamic states in Iran and Syria, and tensions in the Middle East have raised concerns about renewable energy investment for a reliable energy supply (Khan et al., 2023). According to Cheikh and Zaied (2023), geopolitical risk influences the renewable energy transition depending on the level of economic development. Focusing on both developed and developing countries and employing panel regime-switching models, they concluded that adverse geopolitical events prompt developed countries to switch to alternative energy sources. Meanwhile, developing nations should build resilience and accelerate economic growth to reduce geopolitical risk. Taking the example of the USA, Zhang et al. (2023) explored the relationship between green energy consumption, renewable electricity output, geopolitical risk, and natural resource rents. Cointegration analysis indicates that geopolitical risk hampers the renewable energy transition, while economic growth and electricity output significantly influence it. Conversely, different resource rents exhibit varying behaviors. According to Sweidan (2021), geopolitical risk acts as a driver of renewable energy deployment in the US market by promoting energy independence from crude oil to prevent energy scarcity and enhance energy security. Chishti et al. (2023) identified that green technology and green finance exert positive impacts, whereas geopolitical risks hinder renewable energy investments. Similarly, Khan et al. (2023) examined how geopolitical risk impacts environmental policy, which in turn affects renewable energy investment and other sustainable decisions.

GPR also asserts a consequential impact on financial markets and energy stocks. Geopolitical risk influences investor sentiment and investment in renewables, which ultimately leads to higher volatility in energy stocks (Sarker et al., 2023). By analyzing both aggregate and disaggregated index data of geopolitical risks, Qin et al. (2020) found that geopolitical risk has a heterogeneous effect on the return and volatility of various types of energies. Zhao et al. (2023) examined the impact of GPR and economic policy uncertainty on five sub-sectors of renewable energy markets, where results reveal that renewable energy can serve as a time-varying hedge against these risks. Therefore, the literature suggests that geopolitical risks have a dual impact, as they can either hinder or promote investment in renewable energy.

### 2.2. Climate policy uncertainty and renewable energy investment

The climate is changing and has inherited elements of uncertainty. However, it entails financial and economic implications if there are substantial uncertainties in the policies to manage these risks (Sarker et al., 2023). Moreover, renewable energy projects are long-term and capital-intensive initially, requiring careful consideration and consistency in environmental policies, where uncertainty regarding climate policy influences investor sentiment, thus affecting renewable energy investment. Li et al. (2023) asserted that the causal relationships between renewable energy consumption and CPU are both positive and negative, depending on administrative considerations. If the administration has a positive attitude towards climate uncertainties, renewable consumption increases, and vice versa. However, the causal links between CPU and non-renewable energy consumption are positive, indicating that during periods of high uncertainty, non-renewable energy consumption rises. Considering five different types of renewable energy consumption, Xi et al. (2023) found through the Granger causality test that CPU impacts wind and solar energy; however, the time-varying analysis reveals a stronger effect of CPU on energy consumption. Through survey data, Hu et al. (2023) demonstrated that environmental policy influences corporate green investment decisions, and executive environmental awareness significantly moderates the relationship with policy enforcement uncertainty.

According to Dutta et al. (2023), CPU increases investments in green energy and yields higher returns for clean energy stocks. Thus, higher climate risk boosts the returns on clean energy ETFs. Furthermore, Liu et al. (2023) examined the case of the USA to establish links between climate policy uncertainty, coal efficiency, green energy, and green innovation using data from 1990 to 2020. Employing various wavelet methods, the authors argue that CPU reduces carbon emissions over the long term, while coal efficiency mitigates emissions at different frequencies; green energy and green innovation help protect the environment in the short and medium terms. Zhou et al. (2023) collected monthly data and utilized time-varying analysis for the USA to investigate the relationship between CPU, different types of renewable energy consumption, and oil prices. Results reveal a heterogeneous relationship between CPU and energy consumption, as well as confirm the fluctuating nature of these variables. CPU influences oil prices in the short and medium term, whilst affecting energy consumption in both the short and long term. Therefore, the existing literature on this significant factor presents evidence supporting both positive and negative impacts; it may foster energy development or hinder it.

### 2.3. Environmental policy and renewable energy investment

REI is the core of environmental protection and climate change reduction, which requires policy development and a clear focus from top management. It is equally important to enforce policies and make them stringent for effective implementation. EP aids in conserving resources and improving efficiency, supporting the transition to renewable energy and sustainability (Ullah et al., 2023). According to Niu et al. (2022), EP assists in adopting the energy transition and public R&D in renewable energy within OECD countries, establishing bidirectional links. Furthermore, the authors highlight environmental governance as essential for a steady shift towards a greener economy. Using the panel threshold model for OECD countries, Li and Shao (2023) demonstrated that financial policy has a more positive impact on renewable energy innovation when it becomes more stringent. When market forces are insufficient to curb environmental degradation, government policy interventions can play a crucial role. Environmental rules and regulations decrease carbon emissions through technological innovation, which also promotes the development of alternative energy sources (Liu et al., 2023). Alsagr (2023b) examined the asymmetric impact of environmental policy stringency on renewable energy investment in BRICS economies, revealing that positive shocks in EP increase renewable

energy investment both in the short and long term.

Environmental taxes have been the point of interest to probe the marginal impact of environmental policies on sustainability. Effective implementation of environmental regulations directs financial resources towards sustainability; therefore, the role of financial development enhances the effect of EP on energy transition (Liu et al., 2023). Chu (2023) examined the asymmetric impact of EP and environmentally related technologies on renewable energy development in OECD countries. The analysis reveals interesting yet significant findings, showing that EP exerts a positive impact at low and medium levels, while at higher levels, its impact becomes negative, confirming the green paradox effects. Consequently, countries initially at the energy development stage should adopt stringent policies, whereas those at a later stage should also account for the adverse effects of policy stringency. Similarly, some authors have found that EP is a major contributor to consumption-based carbon emissions. Therefore, environmental governance requires substantial change and increased conservation of renewable energy to combat climate change (Xie et al., 2023). Overall, the literature highlights that environmental policies have favorable effects on sustainability and clean energy investment; however, excessive stringency can sometimes produce opposite results.

#### 2.4. Financial integration, efficiency, and renewable energy investment

Additionally, REI heavily depends on financial stability, integration, and efficiency. Green energy projects are capital-intensive and require strong financial flows, which is only achievable with good financial integration (Dutta et al., 2023). Financial development might cause environmental degradation by increasing the demand for consumer goods that boost carbon intensity. However, in the long run, it promotes environmental and renewable energy technologies, helping develop clean energies and improve energy efficiency (Usman et al., 2024). Financial support plays a crucial role in steering the financial system towards sustainability, especially in renewable energy investment. Due to the long payback period and high initial costs, renewable energy projects need significant financial support (Liu et al., 2023).

Financial integration or globalization enhances Mexico's capacity and safeguards environmental quality by fostering renewable energy technologies and investments in green projects (Raihan et al., 2023). Financial development positively influences the energy transition, while environmental policies have the most substantial effect on it when moderated by financial development (Liu et al., 2023). Ramzan et al. (2023) explore the influence of green innovation and financial globalization on the energy transition and ecological sustainability through the bootstrap rolling window method, revealing a negative impact of financial globalization on energy transition. Similarly, favorable shocks in financial globalization were found to increase emissions. Alsagr (2023a) examined the symmetrical and asymmetrical effects of financial efficiency on renewable energy investment across 23 developed and developing countries, showing that increases in financial efficiency encourage investment in clean energy, whereas decreases have the opposite effect. Ji and Zhang (2019) argue that financial development is the key driver of renewable energy growth, explaining 42.2 % of the variation; they also identify the capital market as the most vital factor in promoting clean energy development. Overall, the literature presents mixed findings; many authors suggest that the impact of financial efficiency and integration on renewable energy development is positive when accompanied by effective environmental management.

#### 2.5. Gap in literature

A thorough review of the literature shows that geopolitical risk, climate policy uncertainty, environmental policy stringency, financial integration, and efficiency play a significant role in renewable energy development. However, despite this evidence, policymakers are still seeking viable policy instruments to encourage renewable energy

investment. The literature reports both positive and negative evidence regarding these factors' impact on renewable energy development, highlighting the need for a unique combination of policies that can support renewable energy investment for the study's sample. As the central and largest influencer of the world economy, the literature on the USA in this context remains relatively limited. Furthermore, existing studies provide evidence of these predictors for different variables of interest; for example, most previous research has focused on renewable energy consumption (Li et al., 2023; Ullah et al., 2023; Xi et al., 2023), volatility and returns of clean energy prices (Sarker et al., 2023), or environmental quality (Assamoi and Wang, 2023), but less is known about renewable energy investment. Notably, the available literature on renewable energy investment has employed different measures, such as energy production, renewable energy consumption, or total energy production and consumption. However, no one has quantified investment in terms of a dollar amount to reflect real-time investment. Additionally, most studies have used various proxies as indicators of environmental regulation, with the index developed by the OECD often overlooked (Alsagr, 2023b). Moreover, the literature suggests that the financial sector has significant potential to promote renewable energy investment, but this area remains less explored (Liu et al., 2023).

The present study addresses all these aspects and focuses on the USA economy. Additionally, it utilizes comprehensive indices for environmental policy, geopolitical risk, climate policy uncertainty, financial integration and efficiency, as well as oil prices and economic growth. The author suggests that oil prices significantly impact investment in alternative energy due to the 'Substitutive Effect' (Li and Shao, 2023), and that the level of economic growth influences renewable energy investment, particularly through the 'Technical Effect' channel when economies reach a certain growth threshold (Guloglu et al., 2023). In essence, the study offers detailed insights into these key macroeconomic factors affecting renewable energy investment in the USA, providing both empirical evidence and theoretical backing for a sustainable future.

### 3. Theoretical framework

This section explains the theoretical framework describing how geopolitical risk, climate policy uncertainty, environmental policy, financial integration, financial institutions' efficiency, oil prices, and economic growth influence renewable energy investment. The global shift toward a sustainable and low-carbon economy greatly depends on investments in renewable energy sources. However, achieving ecological sustainability and rapidly investing in renewable energy both rely heavily on stable economic conditions, technological advances, and effective governance. Geopolitical risk, which includes wars, political tensions, terrorism, conflicts, and international uncertainty, has become a key factor influencing renewable energy investment decisions. GPR can cause economic uncertainty, disrupt vital supply chains, and shift policy focus away from sustainability goals, all of which can impede a country's green growth efforts. Economic uncertainty makes renewable energy transition initiatives less appealing and reduces the effectiveness of policy measures. For example, rising GPR increases uncertainty, discouraging investors from making long-term commitments to renewable energy technologies. Additionally, GPR can slow the transition to renewable energy by causing economic shocks like inflation and instability. As a result, companies and businesses tend to delay their decisions to participate in the energy transition due to higher costs associated with renewable energy technologies. Based on this, we assume a negative relationship between GPR and REI ( $\beta_1 = \frac{\partial REI}{\partial GPR} < 0$ ).

Additionally, climate policy uncertainty significantly impacts investment in renewable energy. The CPU can impede renewable energy investment by creating uncertainty about future policies, subsidies, and market conditions. Strict environmental policies are crucial for encouraging renewable energy investments. However, uncertainty about their design, implementation, or continuation introduces risks

that discourage long-term capital commitment to renewable energy projects. Unpredictability in climate policy caused by political instability, leadership changes, or lack of international consensus may cause investors to delay or abandon renewable energy projects due to increased risks and uncertainty regarding future returns. Conversely, the CPU can also serve as a catalyst for promoting renewable energy investment. This relationship relies on the idea that greater uncertainty about future climate policies, such as the potential for stricter carbon pricing, emission limits, or the ending of fossil fuel phase-outs, can prompt firms and investors to proactively shift toward renewable technologies in anticipation of tighter regulations. Furthermore, the CPU may amplify market volatility, encouraging institutional investors to reallocate their portfolios toward more sustainable and resilient assets, including renewable energy projects. Therefore, we expect that the CPU can influence REI both positively and negatively ( $\beta_2 = \frac{\partial REI}{\partial CPU} > 0$ ) or ( $\beta_2 = \frac{\partial REI}{\partial CPU} < 0$ ).

Furthermore, the development and implementation of strict environmental policies significantly influence renewable energy investments. Environmental policies, such as carbon pricing, feed-in tariffs, green subsidies, and renewable portfolio standards, create favorable market conditions for the development and deployment of renewable energy technology. These policy tools reduce investment uncertainty and enhance the financial viability of green initiatives by optimizing risk and return for investors. Additionally, strict environmental regulations demonstrate a sustained government commitment to decarbonization, boosting investor confidence and attracting private capital to the renewable sector. Moreover, environmental policies encourage technological innovation by supporting research and development (R&D). For example, renewable energy projects are the most costly, so providing subsidies and tax incentives for clean energy initiatives can lessen the initial investment burden. Environmental policy stringency also serves as a signal of long-term regulatory stability, which is critical in de-risking renewable infrastructure investments with long payback periods. Therefore, we hypothesize a positive relationship between EP and REI ( $\beta_3 = \frac{\partial REI}{\partial EP} > 0$ ).

Financial integration, which explains how a country's financial system connects with global capital markets, plays a crucial role in encouraging investment in renewable energy by boosting capital mobility, facilitating the sharing of technological information, and supporting investor diversification strategies. The openness of the financial system can attract foreign private investment, which is essential for closing the green financing gap. Additionally, financial integration allows for risk sharing across borders, which enhances investor confidence in renewable energy projects with long-term growth potential. Thus, we assume that FI positively impacts REI ( $\beta_4 = \frac{\partial REI}{\partial FI} > 0$ ).

Furthermore, the transition from traditional to renewable energy sources presents several challenges. A significant obstacle is the high initial cost of renewable energy projects, including infrastructure and operational expenses. Therefore, a strong financial infrastructure significantly influences investment levels in the renewable energy sector. Well-established financial institutions and markets reduce information asymmetry and transaction costs, making funding for renewable energy projects more accessible and affordable. Additionally, these financial institutions can enhance funding by offering specific green financing tools such as green bonds and sustainability-linked loans. Thus, we assume that the financial institutions' efficiency positively influences the renewable energy investment ( $\beta_5 = \frac{\partial REI}{\partial FIE} > 0$ ).

Furthermore, oil prices significantly influence renewable energy investment decisions. For example, rising OP increase the cost of energy derived from fossil fuels, making renewable energy sources considerably

more attractive. This relationship is well-explained by the substitution effect, where the opportunity cost of using fossil fuels over clean energy becomes too high during oil price surges, thereby redirecting investments toward renewables. Additionally, a rise in OP heightens energy security concerns, which in turn encourages governments and businesses to diversify their energy sources and reduce reliance on volatile fossil fuel markets. Moreover, increasing OP often promotes innovation and government support for renewable energy technologies. Conversely, a decline in OP makes traditional energy sources relatively cheaper, potentially discouraging investment in renewable projects. Furthermore, a drop in OP may lessen the need for energy diversification and reduce enthusiasm among consumers and policymakers for alternative energy sources. Based on this reasoning, the study assumes that fluctuations in OP can impact renewable energy investment either positively ( $\beta_6 = \frac{\partial REI}{\partial OP} > 0$ ) or negatively ( $\beta_6 = \frac{\partial REI}{\partial OP} < 0$ ).

Additionally, economic growth is a key driver of investment in the renewable energy sector. Keynesian and neoclassical economic theories suggest that an increase in economic growth raises the level of national income, which enhances the investment capacity of both the public and private sectors. As economic growth rises, governments become more financially able to invest in renewable energy projects. Meanwhile, the private sector also gains funds and confidence to participate in capital-intensive, long-term renewable energy initiatives. Moreover, the Environmental Kuznets Curve hypothesis states that during early stages of economic development, environmental degradation tends to increase; however, after reaching a certain point, countries begin investing in renewable energy and environmentally friendly projects (Grossman & Krueger, 1995). Additionally, the theory of innovation argues that wealthier nations have a greater capacity to fund renewable energy R&D, leading to technological advancements and cost reductions in the sector. Another crucial factor driving investment in renewable energy sources is the need to ensure energy security. The desire for energy security and affordability further motivates renewable energy investments. A prosperous nation can diversify its energy sources to mitigate risks associated with geopolitical instability and dependence on fossil fuels. Thus, economic growth serves not only as a financial enabler but also as a technological and institutional catalyst for renewable energy investment. Thus, economic growth positively affects the REI ( $\beta_7 = \frac{\partial REI}{\partial GDP} > 0$ ).

## 4. Data and methodology

### 4.1. Variables and data

This research project explores the relationship between geopolitical risk, climate policy uncertainty, environmental policy, financial integration, financial institutions' efficiency, oil prices, GDP, and renewable energy investment in the USA. For this purpose, we use annual time series data spanning from 1990 to 2022. The chosen time frame is solely based on data availability. Table 1 below provides descriptions of the parameters and data sources. Additionally, before proceeding with the empirical analysis, the study examines the visual aspects of the data presented in the time plots shown in Fig. 1.

### 4.2. Model specification

The primary aim of this study is to empirically examine the influence of geopolitical risk (GPR), climate policy uncertainty (CPU), environmental policy (EP), financial integration (FI), efficiency of financial institutions (FIE), oil prices (OP), and GDP on renewable energy investment (REI) in the USA. For empirical analysis, this study employed the innovative DYARDL model. This advanced econometric approach

**Table 1**  
Data description.

Variables	Symbol	Measurement	Source
Renewable energy investment	REI	2015 PP US\$ (millions)	IEA
Geopolitical risk	GPR	A high level of index indicates a high level of geopolitical risk	Caldara and Iacoviello (2022)
Climate policy uncertainty	CPU	Index	Policy uncertainty
Environmental policy	EP	EP stringency index	OECD
Financial integration	FI	Financial globalization index	KOF
Financial Institutions efficiency	FIE	Financial institutions efficiency	IMF
Gross domestic product	GDP	Per capita constant 2015 US\$	WDI
Oil price	OP	Per barrel US\$	Statista

overcomes the limitations of the traditional ARDL model when analyzing multiple factors in both the long run and the short run. Additionally, this method is particularly effective for capturing the actual variation in the dependent variable caused by the independent variables. We have formulated the basic model to explore the relationship between the variables as follows:

$$REI = f(GPR, CPU, EP, FI, FIE, OP, GDP) \tag{1}$$

Furthermore, taking into account the intercept and coefficient terms, Equation (1) can be expressed as follows:

$$REI_t = \beta_0 + \beta_1 GPR_t + \beta_2 CPU_t + \beta_3 EP_t + \beta_4 FI_t + \beta_5 FIE_t + \beta_6 OP_t + \beta_7 GDP + \varepsilon_t \tag{2}$$

Where  $\beta_0$  indicates the constant term,  $\beta_1 - \beta_7$  depicts the coefficient associated with the explanatory variables, and  $\varepsilon_t$  denotes the error term. Fig. 2 below illustrates the flowchart of the methodological steps that we adopted in this research to effectively implement the novel dynamic simulated ARDL model.

### 4.3. Stationarity test

This study starts with evaluating the stationarity properties and the integration levels of the underlying variables. Stationarity is a crucial aspect of time-series models. Ambiguous empirical results may occur if the series contains a unit root and the order of integration is incorrect. Therefore, it is vital to examine the stationarity of the variables before applying the bounds-testing approach. Additionally, the key condition for implementing the novel DYARDL model is that the measured variable must be integrated at I(1), while the regressors can be at I(0) and I(1), or a combination of both. Conversely, the variables cannot be integrated at I(2). For this reason, we employed the Augmented Dickey-Fuller (ADF) and Phillips and Perron (PP) unit root tests.

### 4.4. Cointegration approach

Before applying the novel DYARDL technique, it is crucial to conduct cointegration testing to verify the long-term relationship between the variables under investigation. For this purpose, the study employed the ARDL cointegration method proposed by Pesaran et al. (2001).

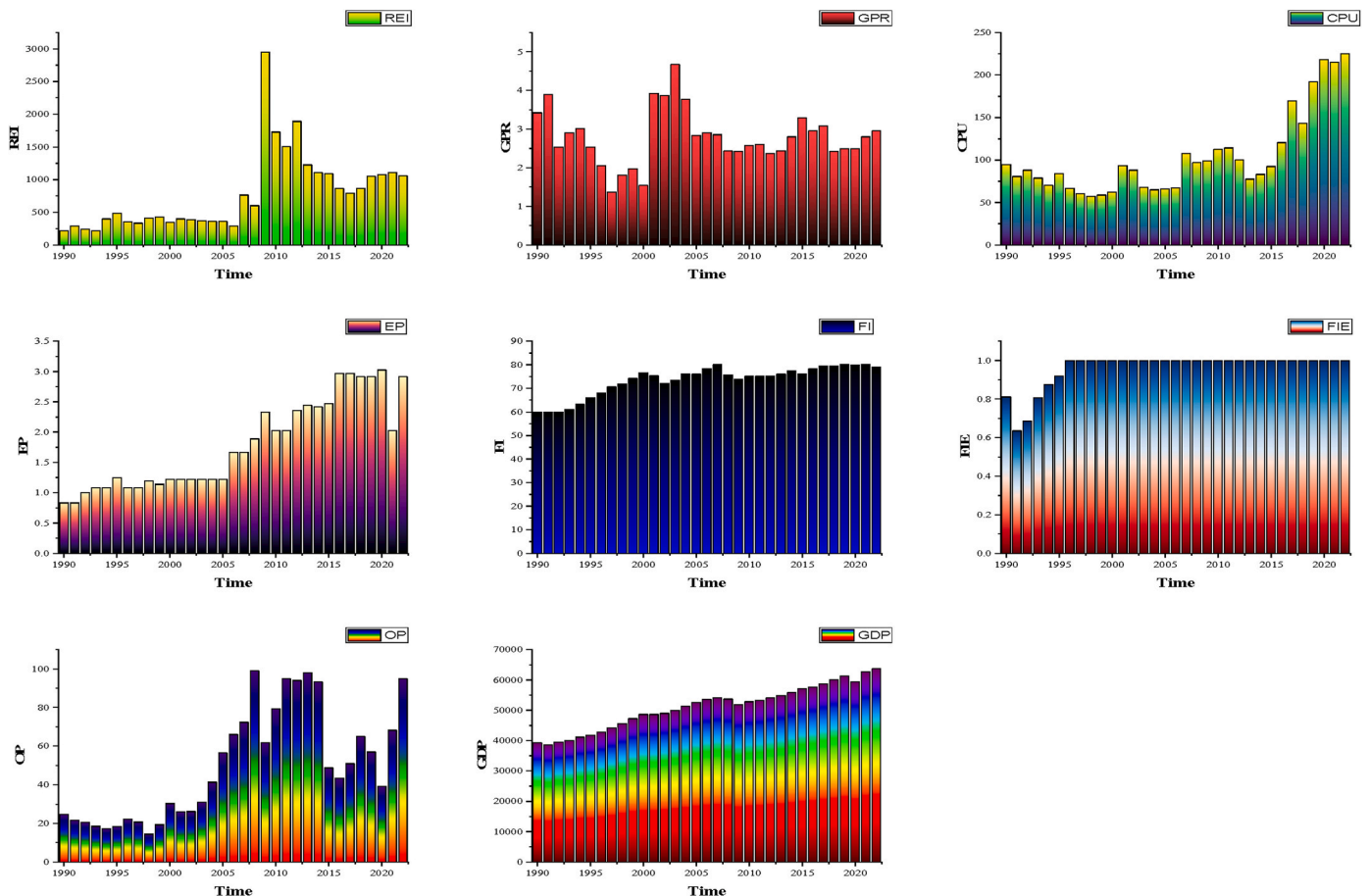


Fig. 1. Trends of variables.

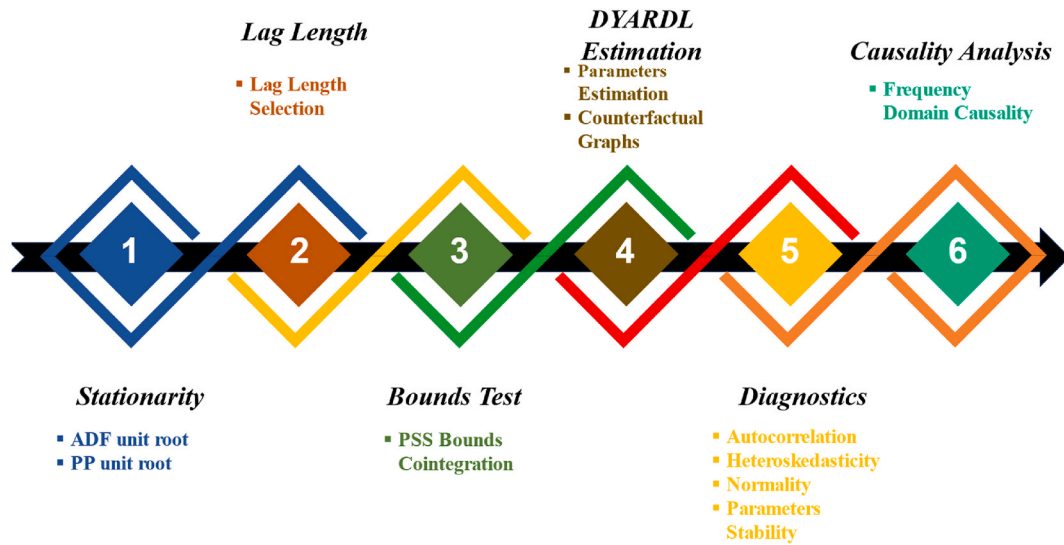


Fig. 2. Methodological flow chart.

Following Pesaran et al. (2001), the equation for the bounds test model is constructed as follows:

$$\begin{aligned} \Delta REI_t = & \varphi_0 + \varphi_1 REI_{t-1} + \varphi_2 GPR_{t-1} + \varphi_3 CPU_{t-1} + \varphi_4 EP_{t-1} + \varphi_5 FI_{t-1} \\ & + \varphi_6 FIE_{t-1} + \varphi_7 OP_{t-1} + \varphi_8 GDP_{t-1} + \sum_{i=1}^p \beta_1 REI_{t-i} + \sum_{i=1}^q \beta_2 GPR_{t-i} \\ & + \sum_{i=1}^q \beta_3 CPU_{t-i} + \sum_{i=1}^q \beta_4 EP_{t-i} + \sum_{i=1}^q \beta_5 FI_{t-i} + \sum_{i=1}^q \beta_6 FIE_{t-i} \\ & + \sum_{i=1}^q \beta_7 OP_{t-i} + \sum_{i=1}^q \beta_8 GDP_{t-i} + \varepsilon_t \end{aligned} \quad (3)$$

In this context, "Δ" reveals the first difference; p and q denote the lags for dependent and independent variables, respectively. t – 1 represents the suitable lags. According to Pesaran et al. (2001), to establish the cointegration connection among variables, we test the following hypothesis:

$$H_0 = \varphi_1 = \varphi_2 = \varphi_3 = \varphi_4 = \varphi_5 = \varphi_6 = \varphi_7 = \varphi_8 = 0$$

$$H_1 \neq \varphi_1 \neq \varphi_2 \neq \varphi_3 \neq \varphi_4 \neq \varphi_5 \neq \varphi_6 \neq \varphi_7 \neq \varphi_8 \neq 0$$

We utilize the bounds F-statistic test to assess the hypothesis. The null hypothesis (H<sub>0</sub>) of ARDL bounds F-statistic states the absence of a cointegration connection between the examined variables. In contrast, the alternative hypothesis (H<sub>1</sub>) defines the presence of a long-term cointegration relationship. The acceptance and rejection of (H<sub>0</sub>) of the bounds test is based on the estimated F-statistic value. In order to establish long-term cointegration, the F-statistic is compared to the lower and upper bound critical values, and the possible outcomes are as follows:

- F-statistics > the upper bound threshold value (existence of long-run cointegration).
- F-statistics < the lower bound threshold value (absence of long-run cointegration).
- F-statistics lies between the higher and lower crucial boundaries (inconclusive outcome)

#### 4.5. Dynamic simulated ARDL approach

Following the establishment of cointegration, this research employed the novel dynamic simulated ARDL model to demonstrate the short-run and long-run estimates of our proposed model. Recently, many

researchers have applied this new approach in the literature (Javed et al., 2023; Aziz and Sarwar, 2023; Hossain et al., 2023a). This novel DYARDL model was developed by Jordan and Philips (2018) to address limitations in the ARDL method of Pesaran et al. (2001). This approach can calculate, forecast, and illustrate fundamental changes in one factor and their effect on the explained variable while holding all other elements constant. Besides evaluating the long- and short-term relationships, this new model can also generate graphs illustrating the effect of positive and negative dynamic counterfactual deviations in explanatory variables on the explained variable (Jordan and Philips, 2018). The DYARDL technique can be used when the variable in question has an integration level I(0), I(1), or a combination of both. To examine the actual changes in the explanatory factors and their influence on the explained, 5000 simulations were conducted based on standard distributions. The resulting figures are used to assess positive and negative shocks in the explanatory factors and their impact on the explained variable. The standard process of the DYARDL method is shown in Equation (4).

$$\begin{aligned} \Delta REI_t = & \alpha_0 + \theta_0 REI_{t-1} + \beta_1 \Delta GPR_t + \theta_1 GPR_{t-1} + \beta_2 \Delta CPU_t + \theta_2 CPU_{t-1} \\ & + \beta_3 \Delta EP_t + \theta_3 EP_{t-1} + \beta_4 \Delta FI_t + \theta_4 FI_{t-1} + \beta_5 \Delta FIE_t + \theta_5 FIE_{t-1} + \beta_6 \Delta OP_t \\ & + \theta_6 OP_{t-1} + \beta_7 \Delta GDP_t + \theta_7 GDP_{t-1} + \varepsilon_t \end{aligned} \quad (4)$$

Where "α<sub>0</sub>" represents the intercept, whereas "θ<sub>is</sub>" and "β<sub>is</sub>" represent the long-term and short-term coefficients, respectively. Additionally, "ε<sub>t</sub>" represents an error term.

#### 4.6. Frequency domain causality approach

Next, we extend our empirical analysis by examining the causal relationships between the explained and explanatory factors of the research. This analysis helps in capturing the extent of causality and the direction of causal linkages between renewable energy investment and its selected parameters, which in turn provides more detailed insights into the validity of the study's primary results. We employed the frequency domain causality (FDC) test suggested by Breitung and Candelon (2006) to identify the causal connections and the direction of causality between the research variables. Unlike traditional causality approaches, this test offers several advantages. One of the primary benefits is its ability to compute the dynamic relationship between two variables across different time intervals. Furthermore, the FDC test can reveal non-linear effects and causality differences, aiding in reducing

seasonality variations in small samples (Abbasi et al., 2021). Therefore, we used the FDC test to determine causal connections, which simplifies the projection of the variable under analysis at specific time frequencies. Based on previous studies, we selected the values of  $\omega_i = 0.05$ ,  $\omega_i = 1.5$ , and  $\omega_i = 2.5$  to assess long-, medium-, and short-term causality. Despite its advantages, this method is limited to a finite time frame and cannot project models over an infinite horizon. Specifically, the formula developed by Breitung and Candelon (2006) is as follows.

$$x_t = \alpha_1 x_{t-1} + \alpha_p x_{t-p} + \beta_1 Y_{t-1} + \beta_p Y_{t-p} + \varepsilon_{1t} \tag{5}$$

The linear constraint of Equation (5) is comparable to the null hypothesis  $M_{Y \rightarrow X}(w)$ . However, the parameters  $\alpha_1$  and  $\beta_1$  are estimated in the time interval  $t$  and lag  $p$ , while the error is denoted by  $\varepsilon_t$ .

## 5. Results and discussion

### 5.1. Descriptive statistics

The initial step in the analysis process is to examine the descriptive characteristics of the underlying variables. The descriptive features of the data set are shown in Table 2. It is clear that both the average and median values of the variables are non-negative. Furthermore, the statistics indicate that GDP has the highest average value (10.830), while EP has the lowest (0.496). Additionally, the standard deviation data suggest that GPR, REI, and OP exhibit the highest volatility. We also conducted kurtosis and skewness analyses to observe the distribution patterns of the series. The kurtosis results show that GPR and FI have heavier tails because their values exceed and remain significantly above the standard threshold of 3. Conversely, the other variables display lighter tails, with values below the set limit. The skewness analysis reveals that REI, GPR, CPU, and EP are positively skewed, whereas FI, FIE, OP, and GDP are negatively skewed. The Jarque-Bera test further confirms that all the variables follow a normal distribution since we cannot reject the null hypothesis of normality, as their p-values are greater than 0.005. Additionally, Fig. 3 presents the box plot summarizing the statistics of the research variables.

Moreover, Fig. 4 illustrates the results of the correlation analysis conducted on the study variables. The evidence shows significant correlations between the variables examined. Specifically, all predictor variables are positively correlated with REI, except for GPR, which is negatively correlated with REI. These findings indicate that increases in CPU, EP, FI, FIE, OP, and GDP are associated with increases in REI. Conversely, a rise in GPR can lead to a decline in REI in the USA. Consequently, these findings pave the way for further research into enduring relationships among these variables.

### 5.2. Stationarity tests

In the next step, we assessed the stationarity properties of our selected factors. To achieve this, we conducted ADF and PP tests. Table 3 below presents the results of the stationarity analysis of the study variables. It is clear from the results of both tests that all the underlying series are non-stationary at the level. However, we observe that after

applying the first difference, the statistics show that all the study variables containing the unit root at the level have become stationary I(1). Consequently, we implemented the innovative dynamic simulated ARDL framework to determine the long-term relationships between REI and its influencing factors in the context of the USA.

### 5.3. Lag length selection criteria

Furthermore, to determine the ideal lag length, the likelihood ratio (LR), the Hannan-Quinn (HQ), the log-likelihood (LL), the Akaike (AIC), the final prediction error (FPE), and the Schwarz Bayesian information criteria (SBC) are used. Table 4 shows the results obtained from these methods. Based on the data in Table 4, the optimal lag length for further analysis is identified as "3".

### 5.4. Cointegration test

The next step in the estimation process is to establish the cointegration relationship among the study variables. This is a crucial step to ensure the accuracy of the results derived from the proposed model. We have used the ARDL cointegration test along with threshold values and approximate p-values recommended by Kripfganz and Schneider (2020) to assess the presence of a long-term relationship among the variables. Table 5 presents the results of the bounds test. The outcomes show that the calculated F-statistic (6.213) and t-statistic (-5.940) exceed the upper bounds thresholds (6.103 and -5.320), respectively, at a 1 % significance level. Additionally, the approximate p-values for the F- and t-statistics, as suggested by Kripfganz and Schneider (2020), are significant. Therefore, based on these results, we reject the hypothesis of no relationship among the variables and support the existence of a long-run connection between the REI and its selected parameters (GPR, CPU, EP, FI, FIE, OP, GDP) in the USA. Given this, it appears appropriate to employ the DYARDL approach to conduct a comprehensive investigation of long-term relationships.

### 5.5. Dynamic ARDL results

As we discussed earlier, this research employed a novel DYARDL model to examine the long- and short-term influence of the explanatory variables on the explained variable (which is REI). This innovative model is a modified version of the traditional ARDL approach that considers the effect of each explanatory variable on the explained variable while maintaining the stability of all other explanatory factors. It also forecasts and visualizes counterfactual variations (negative and positive) in the independent variables, providing a reliable method for assessing the actual impact of the regressors on the measured variable. Table 6 below displays the results of the DYARDL model.

The estimated results indicate that an increase in geopolitical risk significantly negatively impacts REI. This suggests that heightened geopolitical conflicts hinder renewable energy investment in the USA. Specifically, assuming all other factors are constant, a 1 % rise in GPR decreases REI by 0.303 % in the short term and 0.246 % in the long term. These findings align with earlier research (Sohag et al., 2022; Pata et al.,

**Table 2**  
Descriptive statistics.

	REI	GPR	CPU	EP	FI	FIE	OP	GDP
Mean	6.414	2.793	4.558	0.496	4.292	0.548	3.723	10.830
Median	6.181	2.803	4.481	0.511	4.317	0.517	3.768	10.871
Max.	7.991	4.679	5.418	1.109	4.382	0.705	4.596	11.063
Min.	5.381	1.372	4.053	-0.182	4.094	0.387	2.667	10.562
Std.dev.	0.690	0.705	0.395	0.420	0.091	0.083	0.625	0.146
Skewness	0.361	0.460	0.866	0.104	-1.190	0.538	-0.066	-0.390
Kurtosis	2.112	3.476	2.840	1.567	3.166	2.455	1.576	2.090
Jarque-Bera	1.803	1.477	4.164	2.883	7.827	2.002	2.811	1.975
Probability	0.406	0.478	0.125	0.237	0.420	0.368	0.245	0.372

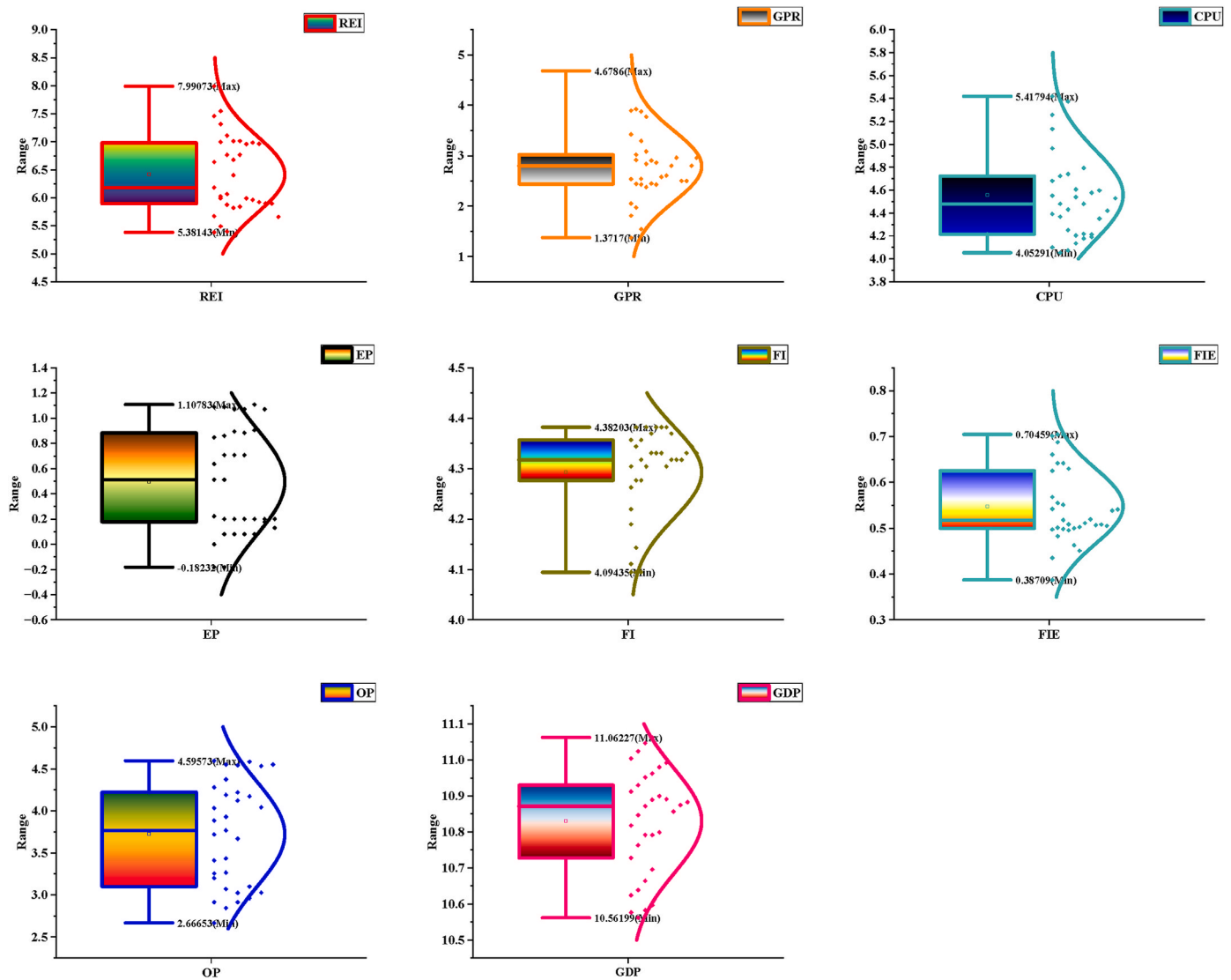


Fig. 3. Box plot summary statistics.

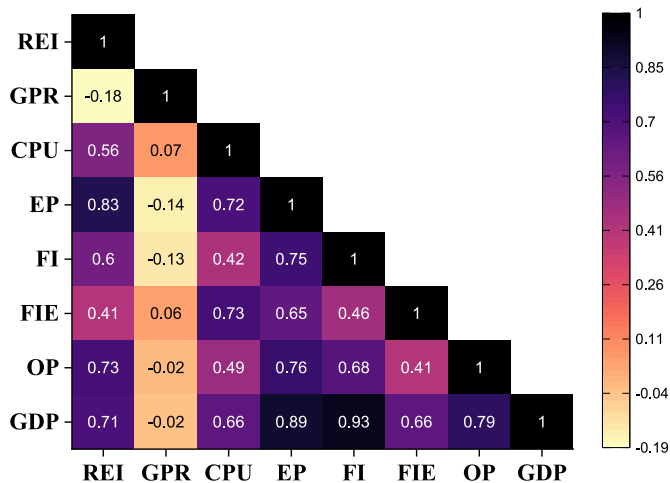


Fig. 4. Correlation graph.

Table 3  
Unit root results.

Variables	ADF		PP	
	I(0)	I(1)	I(0)	I(1)
REI	-1.934	-7.952***	-1.849	-7.798***
GPR	-2.866	-6.413***	-2.965	-6.378***
CPU	-0.366	-5.543***	-0.351	-5.556***
EP	-1.136	-7.595***	-0.978	-7.633***
FI	-2.282	-4.157***	-2.280	-4.109***
FIE	-0.104	-5.648***	-0.738	-5.868***
OP	-0.975	-5.142***	-0.848	-5.136***
GDP	-0.735	-5.645***	-0.789	-5.642***

Note: \*\*\*, \*\* denotes significance levels at 1 % and 5 %.

2023; Flouros et al., 2022; Zhao et al., 2023), all of which reported an adverse effect of GPR on REI. Conversely, results indicate that CPU positively and significantly influences REI. In summary, holding other factors constant, a 1 % increase in CPU results in a 1.312 % rise in REI in the long term and 0.733 % in the short term. This demonstrates that the CPU promotes REI in the USA. Our findings are consistent with (Shang et al., 2022).

Additionally, the results showed that REI has a significant positive

**Table 4**  
Lag length selection-order criteria.

lag	LogL	LR	FPE	AIC	HQIC	SBIC
0	62.968		3.5e-12	-3.665	-3.545	-3.291
1	254.487	383.04	8.4e-16	-12.166	-11.091	-8.803
2	342.304	175.63	5.0e-16	-13.754*	-11.722	-7.402
3	2049.82	3415*	1.3e-61*	-123.21*	-120.333*	-113.98*

**Table 5**  
Cointegration outcomes.

Test statistics	Value	H0	H1			
F-statistics	6.213	No level relationship	Relationship Exists			
t-statistics	-5.940					
Critical and approximate p-values of <a href="#">Kripfganz and Schneider (2020)</a>						
Significance	F-statistics I(0)	I(1)	t-statistics I(0)	I(1)	p-value F I(0)	I(1)
10 %	2.035	3.488	-1.601	-3.733	0.001***	0.009***
5 %	2.520	4.223	-1.999	-4.243	p-value T	
1 %	3.776	6.103	-2.814	-5.320	0.000***	0.004***

**Note:** \*\*\* represents a 1 % level of significance.

**Table 6**  
Dynamic ARDL outcomes.

Variables	Coeff.	Standard error	P-values
$\Delta GPR_{t-1}$	-0.303**	0.106	0.013
$GPR_{t-1}$	-0.246**	0.089	0.015
$\Delta CPU_{t-1}$	0.733*	0.371	0.068
$CPU_{t-1}$	1.312***	0.327	0.001
$\Delta EP_{t-1}$	0.105	0.507	0.839
$EP_{t-1}$	0.530**	0.250	0.036
$\Delta FI_{t-1}$	0.011*	3.055	0.069
$FI_{t-1}$	0.435***	2.538	0.007
$\Delta FIE_{t-1}$	1.622**	0.744	0.055
$FIE_{t-1}$	-0.634	0.885	0.486
$\Delta OP_{t-1}$	0.586**	0.216	0.017
$OP_{t-1}$	0.676***	0.184	0.003
$\Delta GDP_{t-1}$	0.254***	0.354	0.002
$GDP_{t-1}$	0.781***	1.867	0.000
ECT (-1)	-0.754***	0.205	0.002
Constant	6.294	45.785	0.893
R <sup>2</sup>	0.844		
F-statistics(p-value)	(0.002)		
Simulations	5000		

**Notes:** \*\*\*, \*\* & \* represent levels of significance at 1 %, 5 % and 10 %.

relationship with environmental policy. In other words, all else being equal, a 1 % increase in the EP raises the REI by 0.530 % in the long term, while the short-term effect is also positive but not significant. This suggests that implementing strict environmental policies encourages REI in the USA. This finding aligns with the conclusions of [Alsagr \(2023b\)](#), [Ullah et al. \(2023\)](#), [Niu et al. \(2022\)](#), and [Liu et al. \(2023\)](#). Similarly, we found that financial integration positively influences REI in the USA. Specifically, the coefficients for FI indicate that a 1 % increase in FI results in a 0.011 % boost in REI in the short run and a 0.435 % increase in the long run. These results are consistent with previous studies ([Chen & Zhang, 2023](#); [Rahman and Miah, 2017](#); [Gozgor et al., 2020](#)). Overall, these studies suggest that FI promotes investment in renewable energy.

Moreover, the findings demonstrated that financial institutions' efficiency exerts a beneficial impact on REI only in the short run, while the long-term relationship is statistically insignificant. The outcomes suggest that, assuming all other factors remain constant, a 1 % increase in the efficiency of financial institutions leads to a 1.622 % rise in REI. Our

results align with the findings of ([Sohail, 2023](#); [Alsagr, 2023a](#); [Ji and Zhang, 2019](#)). Additionally, the findings show a substantial positive correlation between oil prices and investment in the renewable energy sector in the USA. Specifically, holding all other variables constant, a 1 % increase in oil prices raises renewable energy investment by 0.586 % and 0.676 % over the short- and long-term, respectively. This suggests that rising oil prices encourage investment in the clean energy sector. These results are consistent with the conclusions of [Sweidan \(2021\)](#) and [Li and Shao \(2023\)](#), who argued that an increase in oil prices boosts REI due to substitution effects.

Lastly, the estimated results demonstrate a significant positive relationship between GDP and REI. For example, the results show that, all other factors being constant, a 1 % increase in GDP correlates with a rise in REI by 0.254 % in the short term and 0.781 % in the long term. This notable positive link between GDP growth and REI is also well-supported by earlier research. For instance, [Pata et al. \(2023\)](#) found a positive relationship between GDP and REI in G-7 countries. Similarly, our findings align with those of [Gozgor et al. \(2020\)](#), who identified a beneficial effect of GDP on renewable energy demand in 20 OECD nations. Numerous other researchers, such as [Alsagr \(2023b\)](#), and [Chen and Zhang \(2023\)](#), have also emphasized that higher GDP is a key driver of REI. Furthermore, the estimated coefficient of ECT ranges from 0 to 1, indicating the speed at which the system adjusts towards equilibrium. The significant negative ECT value indicates the rate of adjustment when any shock occurs. Based on the negative and significant ECT coefficient, it can be inferred that deviation from equilibrium will be corrected at a rate of 0.75 over time. Furthermore, we conducted several diagnostic tests to confirm that the estimated model does not have issues with autocorrelation, heteroskedasticity, or normality. The results of these tests are included in the appendix. Based on these results, we determined that our estimated model is free from the problems mentioned above.

### 5.6. Dynamic ARDL forecasts

The novel dynamic simulated ARDL approach has been highly praised in recent literature for its various advantages that the traditional ARDL model cannot offer. One of the most significant benefits of this new approach is its efficient ability to estimate, predict, and visualize forecasts of actual fluctuations in one independent factor and their consequences on the variable being explained, while simultaneously maintaining the stability of the other variables. The impulse responses to 10 % positive and 10 % negative shocks in the independent variables, such as GPR, CPU, EP, FI, FIE, OP, and GDP, and their impact on the explained variable (renewable energy investment) are shown below (see [Figs. 5–11](#)).

The counterfactual response graphs shown in [Fig. 5\(a\)](#) and [\(b\)](#) illustrate predicted changes in REI due to 10 % positive and negative shocks in geopolitical risk. Specifically, [Fig. 5\(a\)](#) shows that a 10 % increase in GPR decreases REI both in the short and long term. Conversely, a 10 % decrease in geopolitical risk increases REI ([Fig. 5\(b\)](#)). This suggests that heightened geopolitical tensions can negatively impact long-term REI in the USA. Furthermore, the response of renewable energy investment to both positive and negative fluctuations in climate policy uncertainty is depicted in [Fig. 6\(a\)](#) and [\(b\)](#). As seen in [Fig. 6\(a\)](#), a 10 % rise in CPU significantly boosts renewable energy investment. Conversely, renewable energy investment declines with each 10 % negative shock in CPU (see [Fig. 6\(b\)](#)).

Furthermore, [Fig. 7\(a\)](#) and [\(b\)](#) show the graphical representation of the expected fluctuations in REI in response to a 10 % increase and decrease in environmental policy. [Fig. 7\(a\)](#) demonstrates that a 10 % positive shock in the EP boosts renewable energy investment. Conversely, a 10 % negative shift in the EP leads to a decline in renewable energy investment ([Fig. 7\(b\)](#)). This indicates that implementing strict EP in the USA encourages investment in the renewable energy sector. Additionally, the plots in [Fig. 8\(a\)](#) and [\(b\)](#) illustrate the

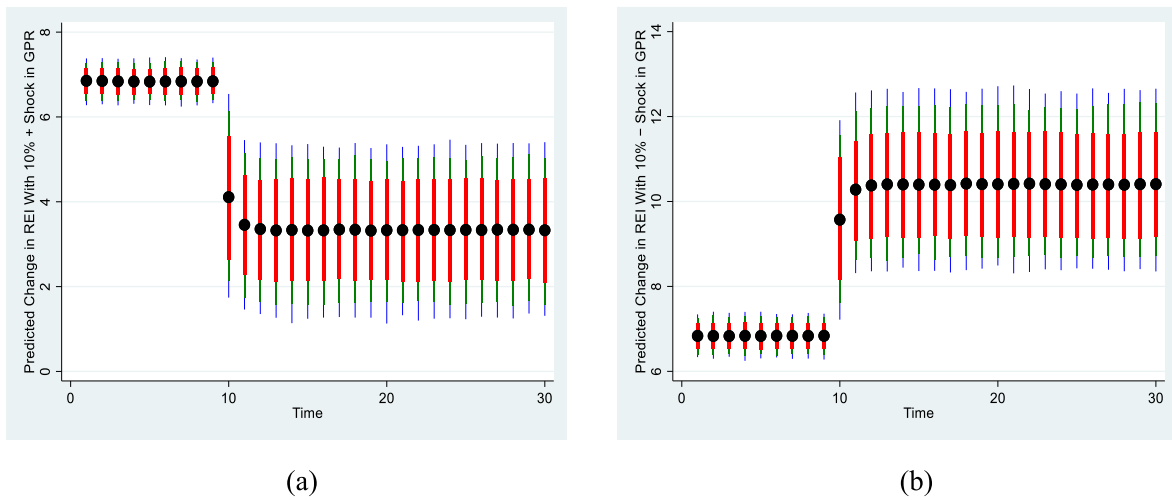


Fig. 5. Graph (a) illustrates a 10 % positive, while graph (b) represents the 10 % negative changes in GPR and its consequence on REI.

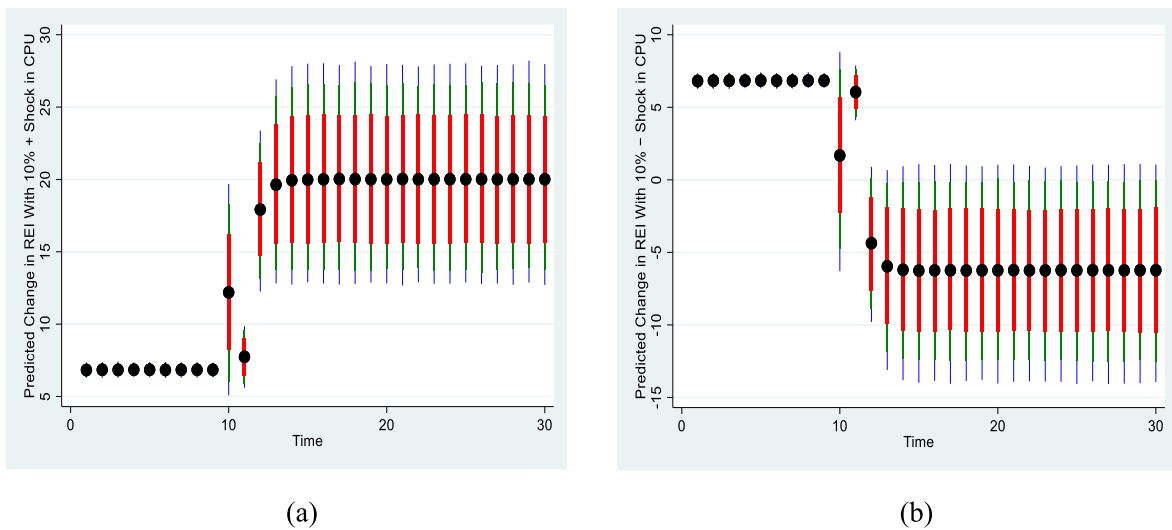


Fig. 6. Graph (a) illustrates a 10 % positive, while graph (b) represents the 10 % negative changes in CPU and its consequence on REI.

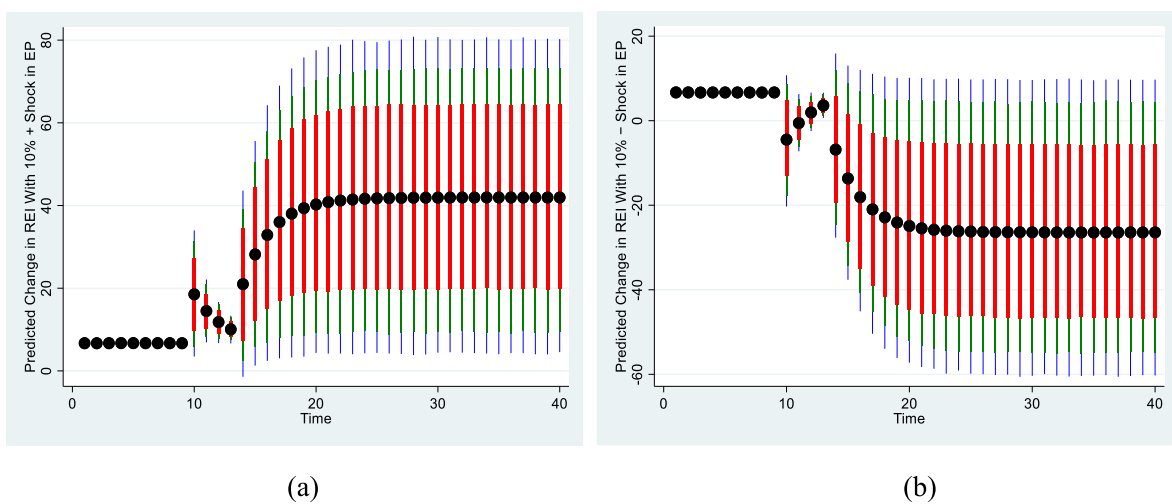


Fig. 7. Graph (a) illustrates a 10 % positive, while graph (b) represents the 10 % negative changes in EP and its consequence on REI.

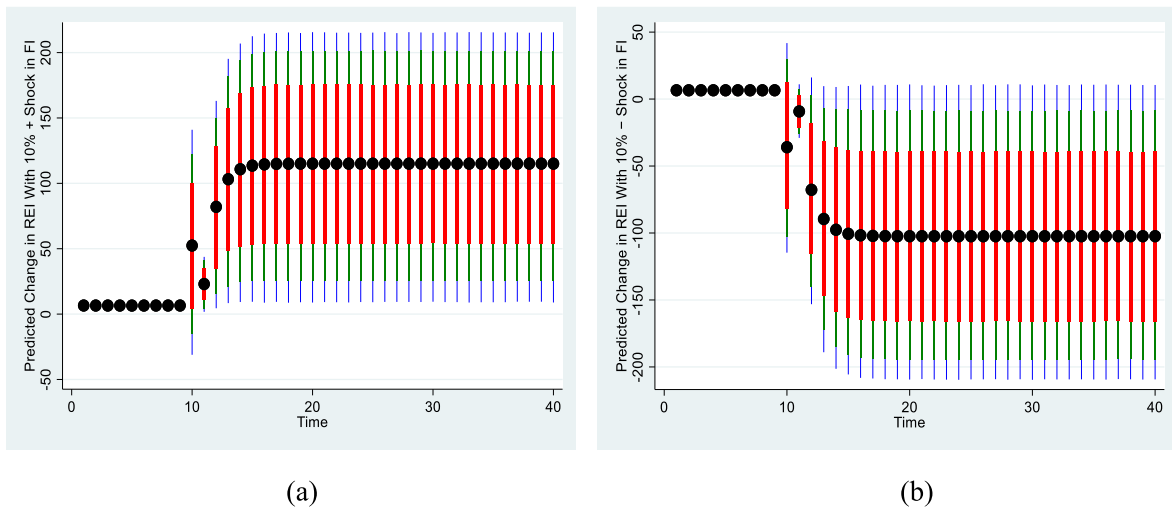


Fig. 8. Graph (a) illustrates a 10 % positive, while graph (b) represents the 10 % negative changes in FI and its consequence on REI.

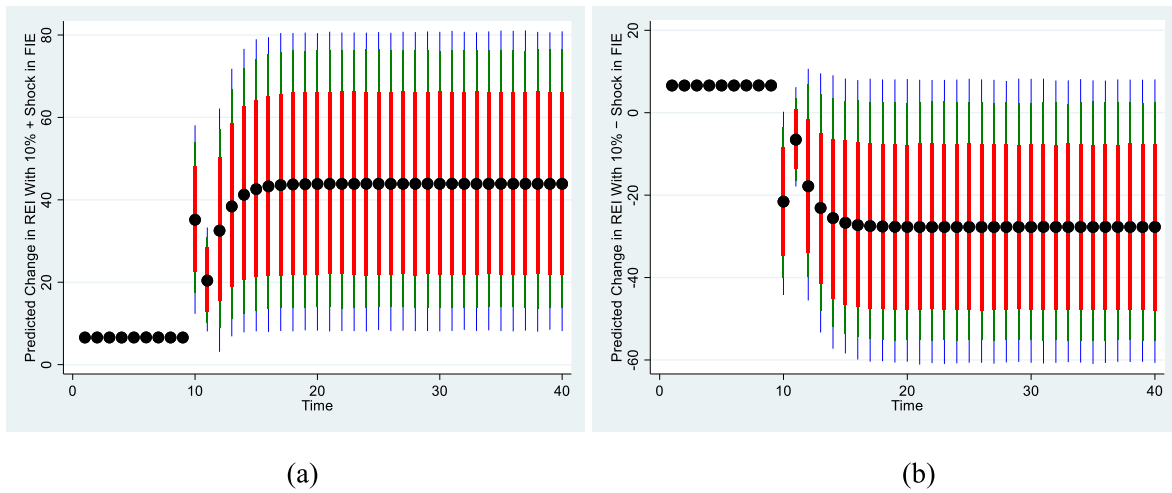


Fig. 9. Graph (a) illustrates a 10 % positive, while graph (b) represents the 10 % negative changes in FIE and its consequence on REI.

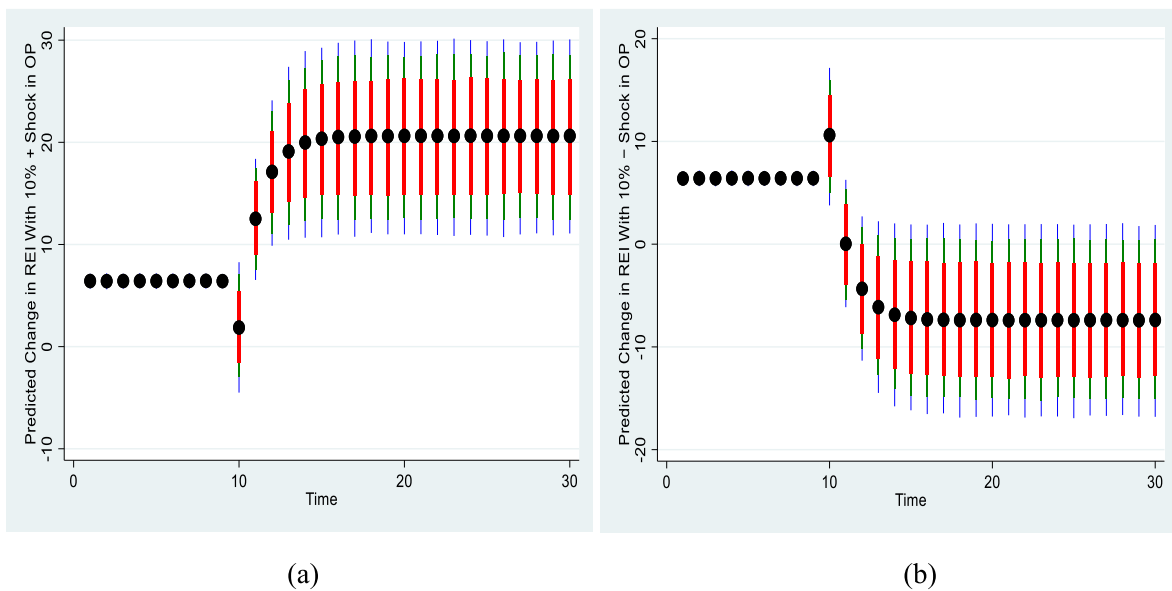
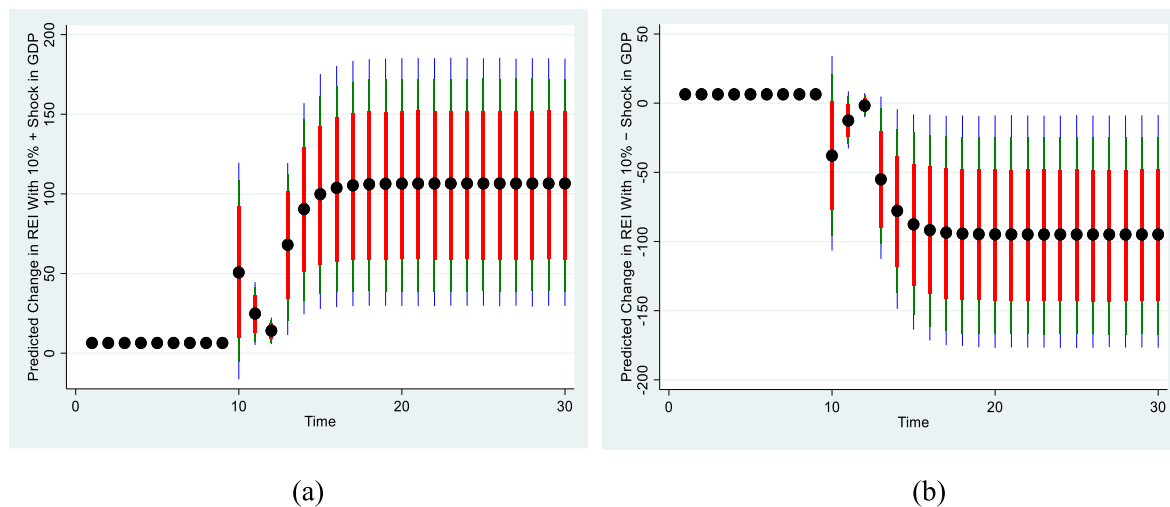


Fig. 10. Graph (a) illustrates a 10 % positive, while graph (b) represents the 10 % negative changes in OP and its consequence on REI.



**Fig. 11.** Graph (a) illustrates a 10 % positive and graph (b) represents the 10 % negative changes in GDR and its consequence on REI.

expected rises and falls in renewable energy investment resulting from a 10 % increase and decrease in the efficiency of financial institutions. Fig. 8(a) highlights that a 10 % positive change in financial institution efficiency promotes REI. Conversely, a 10 % adverse change in financial institution efficiency results in a decline in REI. This suggests that enhancing the efficiency of financial institutions significantly contributes to increasing REI in the USA.

Furthermore, the expected changes in renewable energy investment resulting from both positive and negative shocks in financial integration are illustrated in Fig. 9(a) and (b), respectively. More precisely, Fig. 9(a) shows that every 10 % increase in FI leads to a rise in renewable energy investment. Additionally, a 10 % adverse change in FI tends to cause a significant decline in REI. In conclusion, investment in the clean energy sector is likely to increase with a corresponding rise in financial integration between nations.

Additionally, positive and negative shocks in the oil price response plots shown in Fig. 10(a) and (b) illustrate how a 10 % increase and decrease in the oil price affect renewable energy investment. Specifically, Fig. 10(a) shows that a positive 10 % change in the oil price results in an upward trend in REI. Conversely, a 10 % decline in the oil price hinders REI in the USA, as demonstrated in Fig. 10(b). Furthermore, counterfactual forecasts illustrating both the positive and negative relationships between GDP and REI are presented in Fig. 11(a) and (b), respectively. Based on the graphical representation (Fig. 11(a)), it can be observed that a positive 10 % change in GDP leads to an increase in REI. Conversely, a 10 % negative shock to GDP produces a long-term decline in REI. This outcome suggests that higher economic growth in the USA promotes greater use of cleaner energy and, consequently, boosts renewable energy investment.

### 5.7. Discussion of findings

Over the past few decades, the adoption of clean energy has been viewed as a potential solution to the challenge of meeting the growing energy demand, changing the global energy mix to combat climate change, and reversing environmental degradation (Pata et al., 2023). Compared to traditional energy sources, green energy produces significantly fewer pollutants (Saqib, 2022). Achieving sustainable development globally arguably depends on the transition from conventional to renewable energy sources (Lei et al., 2021). Therefore, investing in cleaner energy is vital to shift away from unsustainable technologies towards those that deliver cleaner energy, supporting stable, environmentally friendly energy supplies and fostering higher economic activity (Pata et al., 2023). However, the dynamics of green energy investment have not been sufficiently explored in the literature, especially in the

USA. Specifically, the roles of GPR, CPU, EP, FI, and FIE, key indicators of clean energy investment, have been overlooked. As a result, this research examines the effects of GPR, CPU, EP, FIE, FI, OP, and GDP on REI in the USA.

The projected estimates of GPR demonstrate a significant negative impact on REI. These estimates indicate that increasing geopolitical conflicts impede REI. This result is not surprising since escalating geopolitical conflicts have the same effect on the economy as political instability, thereby slowing down economic and environmental initiatives. Geopolitical tensions lead to economic instability and raise concerns about the future, even though the country in question has the strongest military and the most robust economy in the world. It is well known that investment in renewable energy projects is deeply linked to political stability and the socio-economic environment. In this context, a rise in geopolitical conflicts might discourage investors from allocating additional funds to complete cleaner energy projects. Moreover, geopolitical risk can hinder REI by causing economic shocks through inflation and uncertainty (Sohag et al., 2022). High inflation and economic uncertainty increase the costs of manufacturing renewable energy projects. Consequently, businesses and companies may be deterred from participating in the energy transition since it makes environmentally friendly solutions more expensive. As a result, the attractiveness of green energy projects declines and the risks associated with these projects rise, leading to a reduction in funding flows and prompting investors to turn to more conventional energy sources. Additionally, both the effectiveness of policy tools and the appeal of renewable energy transition initiatives are undermined when widespread economic and political uncertainty exists. Thus, investors are less inclined to invest further in environmentally friendly energy technologies. Therefore, the USA government and policymakers should consider how GPR impacts various sectors, including the renewable energy transition, especially during periods of geopolitical conflict. Instead of engaging in geopolitical conflicts, it would be more beneficial for the USA and other nations as well to rely on diplomacy to mitigate the adverse effects of geopolitical tensions.

Furthermore, the findings indicate that uncertainty in climate policy positively influences renewable energy investment. Additionally, the research emphasizes the vital role that climate policies in the United States play in encouraging investments in renewable energy by providing financial incentives, mitigating risks, and maintaining long-term market stability. Climate policy can motivate businesses to invest in renewable sources as a way to safeguard against the potential for future regulations favoring low-carbon technologies. This aligns with the findings of (Shang et al., 2022), who suggested that a significant positive impact of CPU on renewable energy consumption exists.

Moreover, it is noteworthy that when climate risk is high, socially conscious investors concerned with environmental issues and the adverse effects of climate change tend to increase their investments in cleaner energy. This could potentially lead to a rise in the value of investments in clean energy (Dutta et al., 2023). Van der Ploeg and Rezaei (2020) highlighted that investment in fossil fuel extraction may decline if climate regulation is enacted. Conversely, renewable and clean energy present substantial opportunities for growth, driven by increasing awareness of environmental protection (Omer, 2008), environmental governance, and policy directions (Su et al., 2023). Consequently, modifications in climate-related regulations will ultimately influence business decisions regarding their energy investments, thereby affecting both conventional and renewable energy sectors (Lei et al., 2021).

Furthermore, the primary findings of our research indicate a significant positive relationship between EP and REI, supported by subsequent rationales. A definition of "stringency" provided by the OECD is "both the explicit and implicit costs linked with environmentally harmful activities." Moreover, imposing a tax on carbon is seen as an additional cost that can discourage the production of hazardous items requiring substantial fossil fuel energy (Hao et al., 2021). This could lead to a shift in the framework governing cleaner energy consumption and output towards more environmentally friendly activities (Mardones and Baeza, 2018). Additionally, due to the enforcement of strict environmental regulations, firms and businesses are encouraged to integrate renewable energy into their production processes, which ultimately boosts the cleaner energy sector (Doğan et al., 2022). It is also considered that rigorous environmental policies influence consumer decisions regarding adoption behaviors (Javed et al., 2023). Such regulations motivate people to utilize clean energy that is more environmentally friendly and cost-effective, since they require businesses and the public to transition towards green energy sources (Du et al., 2021). Moreover, government intervention to promote renewable energy investment and environmental quality initiatives is crucial, regardless of the approaches employed by individuals, companies, and organizations to reduce pollutant emissions from fossil fuel use and to expand renewable energy technologies. Consequently, it is vital to formulate strict environmental measures, which will not only mitigate the harmful impacts of GPR but also direct attention towards the renewable energy sector.

Additionally, the estimated findings of our study demonstrate that an increase in financial integration promotes REI. Financial market integration and the free movement of capital across countries enhance renewable energy investment through various channels. The growing globalization of the financial sector makes it easier for businesses in both developed and developing nations to establish partnerships and joint ventures. This facilitates the transfer of advanced renewable technologies and investment expertise, which in turn lowers the barriers preventing less developed markets from adopting clean energy. Global financial markets also help diversify risks associated with investments in the cleaner energy sector, such as market fluctuations and uncertain government policies. Foreign investors are more inclined to fund projects with higher potential returns if they have diversified portfolios. Through subsidized financing, guarantees, and equity investments, global financial organizations like the International Finance Corporation (IFC), World Bank, and regional development banks play a crucial role in promoting renewable energy. Their support and guarantees reduce project risks, thereby attracting capital from the private sector. The existing literature also supports the positive link between financial integration and renewable energy investment. For example, Gozgor et al. (2020) argued that financial globalization simplifies the process for investors from different countries to invest in renewable energy projects. It also encourages investment by providing easier access to global capital markets. Similarly, Koengkan et al. (2020) showed that FI attracts foreign funds into green energy projects and contributes to the growth of REI. Increasing financing options, reducing borrowing costs, diversifying risks, facilitating expertise transfer, expanding the clean energy market, and creating new jobs are all benefits that the globalization of

the financial sector can bring.

Furthermore, the results of our study indicate a positive connection between the efficiency of financial institutions and REI in the USA. This shows that countries or regions with high incomes and well-developed financial systems can provide a specific mix of efficient financial tools for greener energy investment and innovation. This is because investments in renewable energy involve significant costs for infrastructure, start-up, and operational expenses; a strong financial system and effective risk management are essential (Eren et al., 2019). Therefore, by offering lower interest rates and innovative financial products, efficient financial institutions can reduce the cost of capital, which is crucial for both large-scale and small-scale renewable energy projects. These environmentally friendly energy projects require solid financial guarantees, which depend on the presence of a well-developed financial system (Qin et al., 2021).

Furthermore, clean energy bonds, public-private investment, and flexible loans are some of the innovative concepts that financial institutions are progressively adopting to support renewable energy projects. Brunnschweiler (2010) asserted that the underdeveloped banking sector is unable to efficiently provide loans to renewable energy producers. Contrary to this, Kim and Park (2016) found that nations with developed financial sectors are experiencing a quicker rate of growth in the clean energy sector, which relies more on debt and equity funding. Moreover, the provision of high-quality human capital by nations or regions with highly developed financial systems facilitates easier adaptation to the shift towards green energy (Hashemizadeh et al., 2021). Additionally, an efficient financial system enables households to access cash at low costs to purchase durable goods, and it allows investors to initiate or expand the scale of renewable energy technologies. Furthermore, increased financial inclusion allows investors to shift their investments from industries that are less energy-efficient to those that are more efficient. All these factors contribute to the growing demand for renewable energy investments.

Similarly, the estimated outcomes of the study suggest that a rise in oil prices has a positive effect on renewable energy investment. This favorable relationship indicates that REI is a viable alternative to fossil fuels, as shown by the fact that an increase in oil prices boosts investment in cleaner energy sources in the USA. One possible explanation for this positive relationship is that when the price of oil rises, the cost of energy based on fossil fuels also increases, especially the cost of oil-derived electricity and heating. This makes cleaner energy sources such as wind, solar, and hydropower significantly more attractive. Additionally, despite the high initial costs of clean energy technologies, renewable energy sources are often cost-competitive due to their low or zero fuel costs. Therefore, the substitution effect can lead to an increase in REI in response to rising crude oil prices (Sweidan, 2021; Li and Shao, 2023). Furthermore, developed countries like the USA are heavily reliant on oil imports for their energy needs. They may experience economic pressure from high oil prices, which could encourage these countries to diversify their energy sources. As a result, reducing dependence on oil imports, enhancing energy security, and guarding against fluctuations in oil prices are potential benefits of investing in renewable energy sources.

Lastly, the results show that economic growth in the USA positively influences renewable energy investment (REI). This indicates that higher GDP growth leads to increased energy consumption and more financial resources. Consequently, more funds can be allocated to developing infrastructure and renewable energy sources. It is well known that a higher GDP is a key driver of REI because economic growth boosts national wealth and well-being, resulting in greater resources for environmentally friendly projects (Pata et al., 2023). Wealthier economies like the USA are more likely to have the financial means and institutional capacity to invest in clean energy infrastructure, research, and development. This positive link between renewable energy investment and economic growth has been widely studied and confirmed in academic literature. For example, Lucas et al. (2016) pointed out that

economic growth allows governments and businesses to invest more confidently and boldly in renewable energy technologies. Similarly, [Bamati and Raofi \(2020\)](#) showed that renewable energy output increases as GDP rises, driven by higher investment in industry to meet growing energy demands. Both the public and private sectors now possess the financial resources needed to pursue sustainable energy solutions as the economy expands. The work of [Kilinc-Ata and Dolmatov \(2023\)](#) further confirms that higher GDP plays a crucial role in advancing cleaner energy sources. In conclusion, economic growth acts as a catalyst for clean energy investments by boosting wealth and creating suitable frameworks in finance, technology, and policy.

### 5.8. Frequency domain causality test

In the final stage of the empirical analysis, we employed the frequency domain causality (FDC) approach suggested by [Breitung and Candelon \(2006\)](#). The FDC test illustrates the causal relationships between GPR, CPU, EP, FI, FIE, OP, GDP, and REI in the USA. [Table 7](#) below presents the results of the causality test. Following earlier studies ([Javed et al., 2023](#); [Musa et al., 2024](#); [Hossain et al., 2023b](#)), we used the frequencies of  $\omega = 0.05$ ,  $\omega = 1.65$ , and  $\omega = 2.45$  to identify long-term, medium-term, and short-term causal links between REI and its selected factors. The findings in [Table 7](#) clearly show that GPR Granger causes REI in the long- and short-term but not in the medium-term. Additionally, the results indicate that CPU Granger causes REI only in the medium-term, not in the long- or short-term. Furthermore, there is a causal link between environmental policy and renewable energy investment in the long-term ( $\omega = 0.05$ ), medium-term ( $\omega = 1.65$ ), and short-term ( $\omega = 2.45$ ). The findings also reveal that financial integration Granger causes REI only in the long- and short-term. However, a causal link between FIE and REI is observed only in the medium-term. Moreover, oil prices Granger cause REI across the long-, medium-, and short-term. Finally, there exists a long-term and short-term causal connection between GDP and REI.

In addition, the graphical representation of the frequency domain causality is shown in [Figs. 12–18](#), respectively. More precisely, [Fig. 12](#) also demonstrates that the GPR Granger causes the REI in both the long-term and short-term. Furthermore, it is clear that a one-way causality exists between GPR and REI, with causality running from GPR to REI (see the second panel of [Fig. 12](#)). Additionally, [Fig. 13](#) shows that the CPU Granger causes the REI, and the REI Granger causes the CPU only in the medium-term. This finding suggests a feedback hypothesis between the CPU and the REI. Moreover, [Fig. 14](#) confirms that EP Granger causes the REI, and REI Granger causes the EP across long, medium, and short-term periods, thus indicating a bidirectional connection between EP and REI. Furthermore, the first panel of [Fig. 15](#) indicates that FI leads the REI, while a reverse causality also exists from REI to FI (see the second panel of [Fig. 15](#)). This confirms the presence of a feedback loop within the context of the USA. Additionally, a feedback effect is observed between FIE and REI, OP and REI, and GDP and REI, as shown in [Figs. 16–18](#).

**Table 7**  
Causality outcomes.

Causality	Long-term	Medium-term	Short-term
	$\omega = 0.05$	$\omega = 1.65$	$\omega = 2.45$
GPR => REI	8.324 (0.016)**	2.239 (0.326)	9.345 (0.009)***
CPU => REI	1.332 (0.514)	4.942 (0.085)*	4.401 (0.110)
EP => REI	11.669 (0.000)***	7.088 (0.029)**	10.590 (0.005)***
FI => REI	8.520 (0.014)**	4.844 (0.088)*	2.471 (0.291)
FIE => REI	2.689 (0.261)	4.667 (0.097)*	1.169 (0.557)
OP => REI	12.544 (0.001)***	8.227 (0.016)***	4.979 (0.083)*
GDP => REI	6.247 (0.044)**	4.359 (0.113)	5.435 (0.066)*

**Notes:** \*\*\* & \* indicate the level of significance at 1 % and 5 %, respectively.

## 6. Conclusion and policy recommendations

This research aims to analyze the role of geopolitical risk, climate policy uncertainty, environmental policy stringency, financial integration, and the efficiency of financial institutions on renewable energy investments (REI) in the USA. The choice of the USA is justified for two main reasons. First, due to the size of its economy, energy consumption, and its consequent impact on climate change, the USA will likely need more energy in the near future than it currently does. Second, because of its political complexities and geopolitical risks, there is a need to promote steady growth in renewable energy sources and investments. However, the transition to cleaner energy sources is a slow process, often taking around half a century from initial energy adoption to a significant market share, as evidenced by existing data. Therefore, it is essential to empirically examine the factors affecting renewable energy investments to facilitate a transition that is effective, steady, and swift.

The authors employ modern and innovative econometric techniques to achieve the study’s aims, including the novel dynamic simulation ARDL approach that uses annual time series data from 1990 to 2022. To assess the relationships between the study variables, this approach addresses the limitations of the traditional ARDL model developed by [Pesaran et al. \(2001\)](#). One of its main advantages is its ability to automatically generate and display graphs alongside numerical results. This approach simulates forecasts and visualizes the effects of actual changes, both positive and negative, in the explanatory variable on the dependent variable, while keeping other variables constant. Additionally, the research utilizes the FDC approach to examine the relationships and causal directions between the variables across different time frequencies. When working with multivariate time-series data, stationarity issues often arise. Consequently, unit root tests were conducted to thoroughly analyze the stationarity properties of the variables. The results indicated that the series are stationary and integrated at I(0) and I(1).

Furthermore, the bounds test cointegration results indicate a long-term relationship between the variables of interest. Moreover, the outcomes of the novel dynamic simulated ARDL model demonstrate that GPR has a significant detrimental effect on the REI. This suggests that an increase in GPR hampers the REI in the USA. Additionally, REI shows a positive association with CPU and the implementation of strict environmental policies. Furthermore, the findings reveal that financial integration, the efficiency of financial institutions, oil prices, and GDP positively influence the REI. Also, the FDC test results indicate that GPR, CPU, EP, FI, FIE, OP, and GDP Granger cause the REI at different time frequencies (long, medium, and short term).

Based on the results, it is suggested that although the pathways to renewable energy investment are being developed, they are not sufficient to address the immense energy challenges; therefore, specific policy-level changes are necessary. First, GPR proves to be an obstacle to REI at the same time that the USA’s political, economic, and military interests are spread worldwide. The governance aspect becomes more significant here, requiring a greater focus on renewable energy investment and efforts to reduce geopolitical tensions for economic, environmental, and social prosperity. Secondly, financial development and efficiency are crucial to enhance REI, which also needs to be directed towards sustainable use. The central bank, as the guardian of the financial system, can play a pivotal role in bridging the green financing gap by strictly implementing tax credits and reliefs for renewable energy investments. The USA has already introduced the production tax credit and the investment tax credit to promote solar energy. We propose expanding the range of tax credits across all types of renewable energy investments, enabling companies to effectively utilize them to lower their tax liabilities. Importantly, renewable energy projects require substantial capital investment, especially in their initial years. Considering this, financial institutions with long-term resources, such as insurance companies and pension funds, can be encouraged to support long-term REI projects. Additionally, the issuance of green bonds,

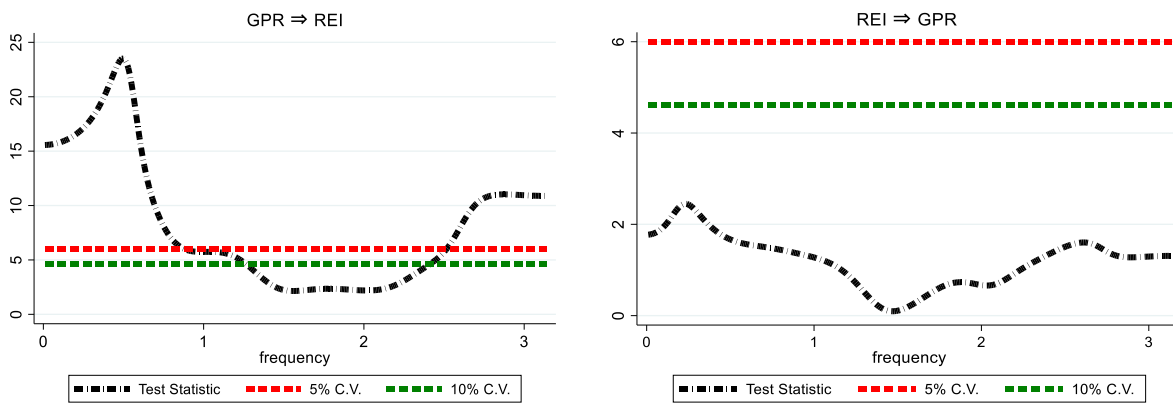


Fig. 12. Graphical visualization of frequency domain causality between GPR and REI.

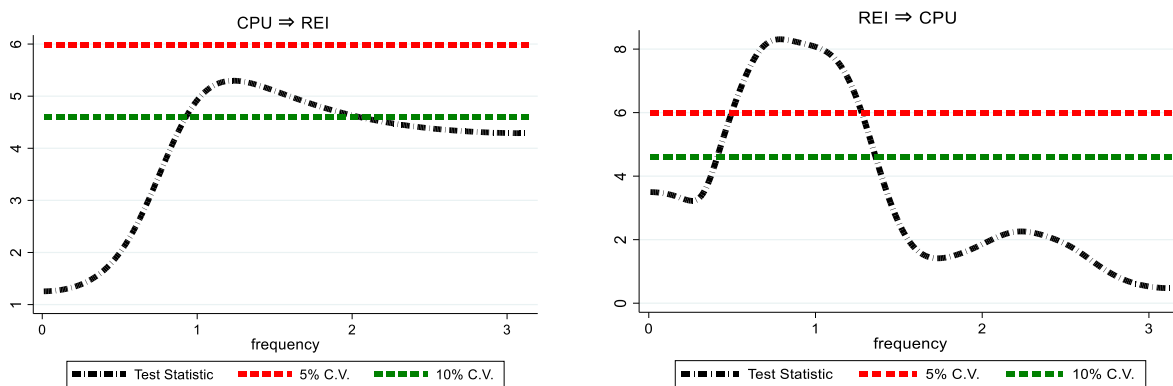


Fig. 13. Graphical visualization of frequency domain causality between CPU and REI.

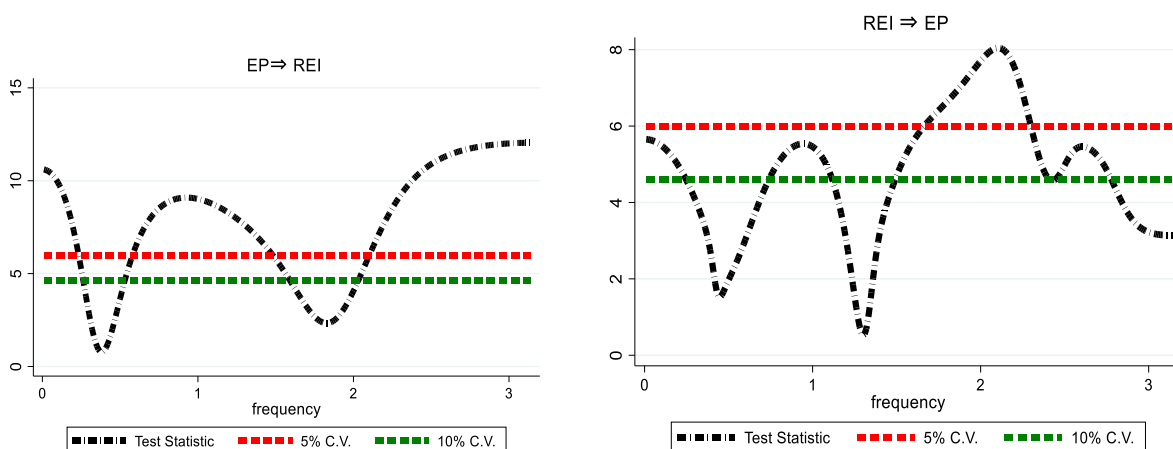


Fig. 14. Graphical visualization of frequency domain causality between EP and REI.

green credit, and other green financial instruments can promote investment in capital markets. Moreover, stringent environmental policies encourage REI, so through "sticks and carrots" or incentivizing the REI policies and penalizing non-compliance with them can play a substantial role. Climate policies for REI should be rigorously formulated, communicated, and executed to reduce ambiguity regarding climate urgencies and involve the masses in a joint project of environmental rehabilitation.

The current study has some limitations that can be addressed in future research. Investigating the governance, organizational, and administrative structures is essential, as they influence energy policies, economic strategies, and environmental regulations. Future studies

should include these important indicators, such as governance quality and institutional quality. Additionally, this study covers the period from 1990 to 2022 based on data availability; future research could extend this period if more data becomes accessible. Future work might also explore the impact of ongoing conflicts, such as those between Ukraine and Russia and Palestine and Israel, on renewable energy investment. Moreover, this study focuses solely on the USA, which faces peak concerns; however, future research could incorporate other developed and developing countries and draw comparative analyses. Finally, future studies could examine the role of these factors in different levels of energy investment, for example, low, medium, and high.

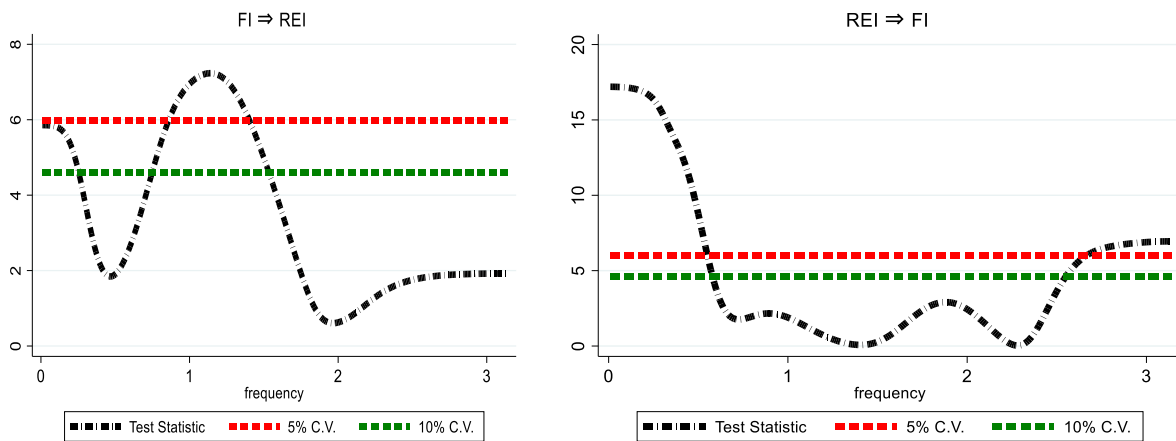


Fig. 15. Graphical visualization of frequency domain causality between FI and REI.

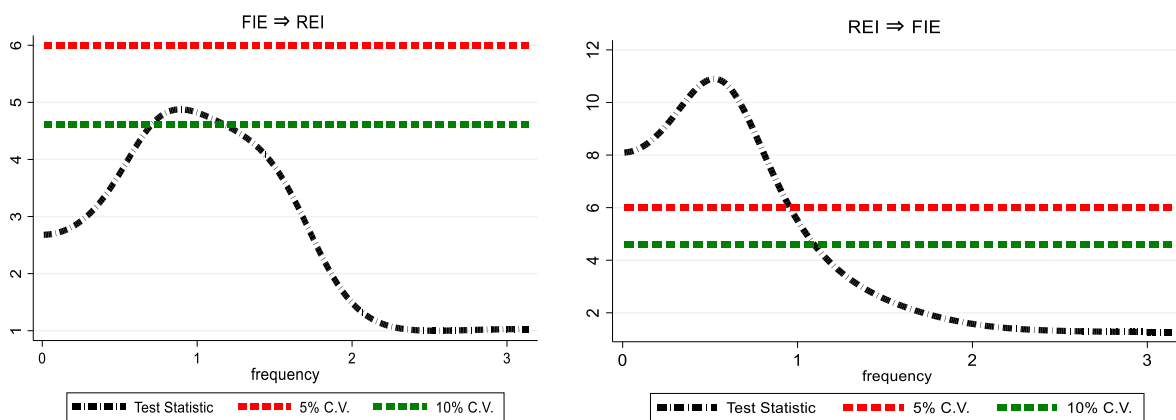


Fig. 16. Graphical visualization of frequency domain causality between FIE and REI.

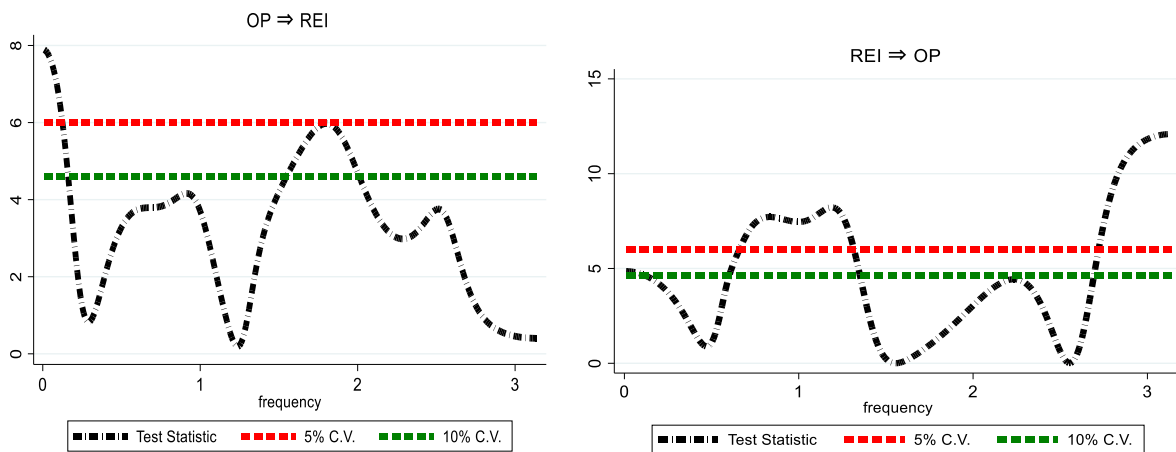


Fig. 17. Graphical visualization of frequency domain causality between OP and REI.

**CRedit authorship contribution statement**

**Aamir Javed:** Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Mahjabeen Usman:** Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Conceptualization. **Nabila Abid:** Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration,

Methodology, Investigation, Data curation. **Agnese Rapposelli:** Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Conceptualization.

**Declaration of competing interest**

The author declares that there is no financial/personal interest or belief that could affect the objectivity of this manuscript.

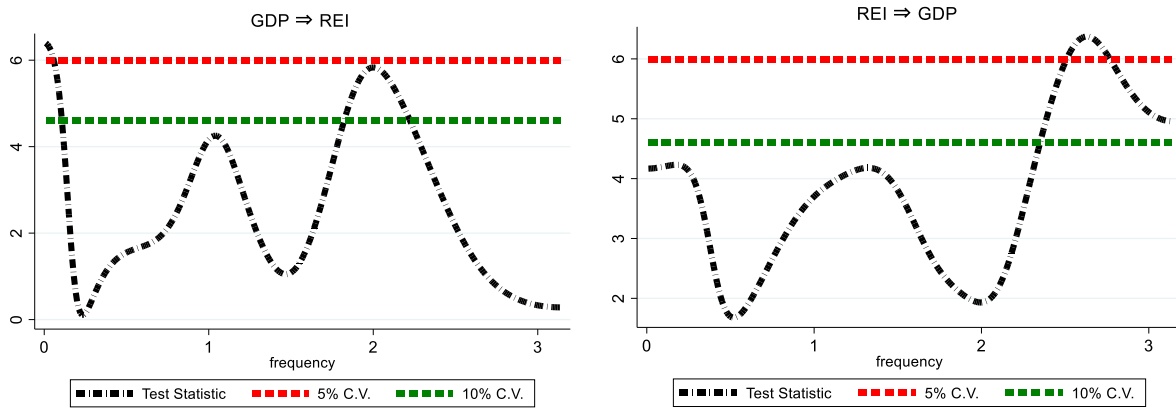


Fig. 18. Graphical visualization of frequency domain causality between GDP and REI.

Appendix

Table A1  
Autocorrelation test by Breusch-Godfrey

Lags	F	Df	Prob > F
1	2.912	(1, 18)	0.1051
2	1.930	(2, 17)	0.1756
3	2.167	(3, 16)	0.1318
4	3.112	(4, 15)	0.4730

Table A2  
Decomposition of the IM-test by Cameron & Trivedi's

Source	Chi2	df	P
Heteroskedasticity	30.00	29	0.4140
Skewness	5.17	14	0.9833
Kurtosis	0.53	1	0.4675
Total	35.70	44	0.8093

Table A3  
Normality test

Variables	Obs	Pr (Skewnss)	Pr (Kurtosis)	Adj Chi2 (2)	Prob > Chi2
Residuals	32	0.4616	0.8832	0.59	0.7463

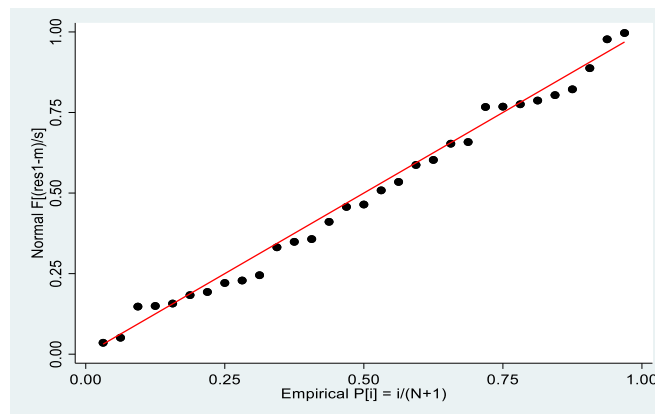


Fig. A1. Plot of standard normal probability

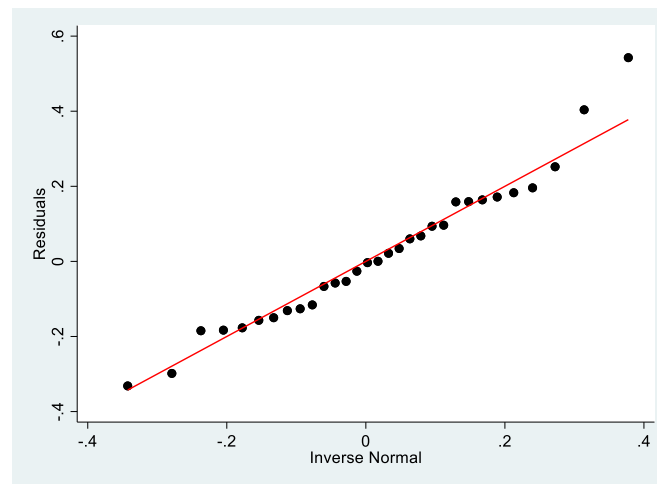


Fig. A2. Normal distribution quantiles versus residuals quantiles

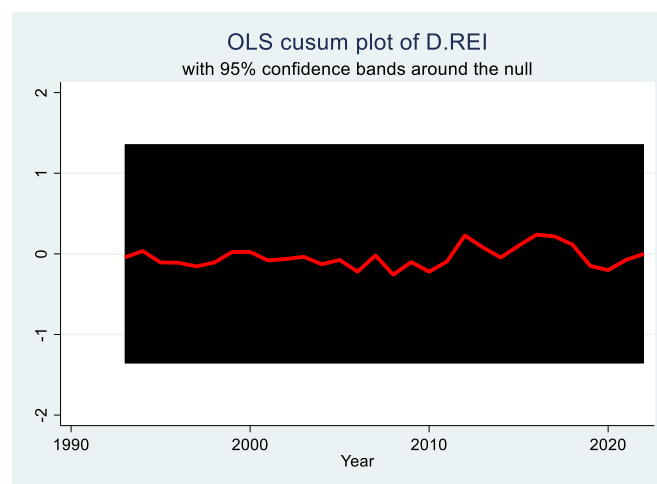


Fig. A3. Parameter stability by OLS CUSUM plot

## Data availability

Data will be made available on request.

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