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Journey to Net-Zero and Investment in Renewable Energy: Evidence From Developed and Developing Countries

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ABSTRACT

This study examines how geopolitical risk, high-technology exports and the Paris Agreement shape investment in renewable energy across developed and developing economies. Drawing on structural contingency theory, we conceptualise renewable energy investment as a country-level response to external contingencies and analyse a global panel of 100 countries from 2007 to 2021. Using OLS, fixed-effects panel models, two-step system GMM and dynamic Difference-in-Differences models, we find that Paris Agreement ratification has a positive effect on renewable energy investment, but only after a 3- to 4-year onset period. Geopolitical risk is negatively associated with renewable energy investment in developed economies, whereas high-technology exports have a positive and robust association in developing economies, particularly after Paris Agreement ratification. This study calls for heterogeneous net-zero strategies to address the external disruptions and trade-related challenges.

1 | Introduction

Globally, countries have reached a consensus on sustainably developing and have signed the Paris Agreement, which is a legally binding international treaty that requires Nationally Determined Contributions (NDCs) to respond to climate change (Christy et al. 2024; Goworek et al. 2018; Griscom et al. 2017; Lacal Arantegui and Jäger-Waldau 2018; Rogelj et al. 2021). The transformation from non-renewable to renewable energy (RE) is vital to slowing global warming, reducing greenhouse gas emissions, stabilising energy prices, managing climate risk and stimulating economic resilience. As part of the Paris Agreement, countries agreed to 'reach global peaking of greenhouse gas emissions as soon as possible [...] and [...] to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century' (van Soest et al. 2021), that is, carbon neutrality (net-zero). To limit the human-induced temperature rise to 1.5°C, RE capacity must grow substantially. Figure 1 shows that solar PV and wind need to increase their share of total capacity by approximately 14% between 2025 and 2030, with global renewable capacity needing to expand by about 4000 GW to meet net-zero targets. Closing this capacity gap requires sustained investment in renewable energy (IRE), which is essential for translating net-zero commitments into actual RE deployment (Khalifa et al. 2022; Vakulchuk et al. 2020).

Countries face growing external pressures, such as international policies, geopolitical risk (GPR) and trade-related factors that may either accelerate or constrain IRE, but how these pressures translate into RE investment across different national contexts remains insufficiently understood. Previous studies

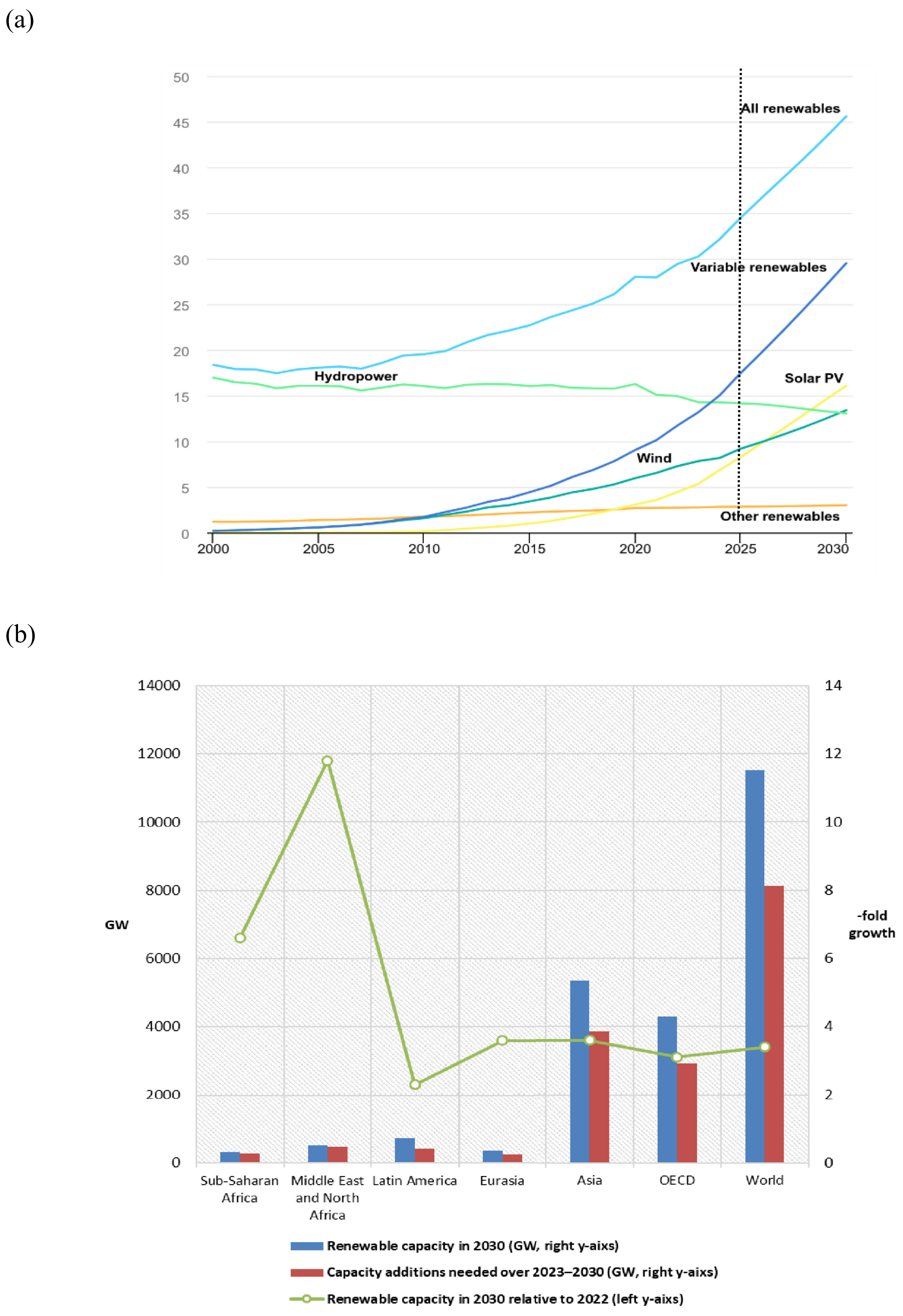

FIGURE 1 | Renewable energy transition pathways. *Note:* Panel (a) shows the share of electricity generated by renewable technology between 2000 and 2030, based on historical records and scenario projections. The variable renewable demonstrates the sum of sola PV and Wind. The dotted line denotes the Year 2025. Panel (b) illustrates the renewable capacity additions needed over 2023–2030 to meet the 1.5°C goal. Values are expressed in gigawatts (GW). *Source:* IEA (https://www.iea.org/data-and-statistics/charts/share-of-renewable-electricity-generation-by-technology-2000-2030) and Climate Analytics (https://ca1-clm.edcdn.com/assets/Tripling-renewables-by-2030.pdf?v=1707761112).

have investigated these aspects in isolation or in region-specific contexts and reported mixed results (e.g., Abbas et al. 2023; Chen et al. 2019; Dinh et al. 2021; Sweidan 2021a, 2021b; Zhao et al. 2023). This paper collects the data from 100 countries (71 developing and 29 developed) over 2007–2021, and employs OLS, fixed-effects panel and two-step system GMM, to distinguishes the divergent effects.

This paper draws on structural contingency theory (SCT) (Lawrence and Lorsch 1967; Shenkar and Ellis 2022; Thompson 2017), which explains how actors adjust internal structures to external contingencies, and extends it to the country level to examine how geopolitical risk (GPR), high-technology exports (HTE) and the Paris Agreement shape national energy strategies and policies in the journey towards net zero.

Our study contributes to the strands of literature on IRE and the global transition toward net zero in the following ways.

First, this study reconciles the mixed evidence on the relationship between GPR and IRE. Rising geopolitical conflicts have reshaped the external environment within which IRE decisions are made. There is dissensus on the influence of geopolitical disruptions and risk on IRE (e.g., Abbas et al. 2023; Sweidan 2021a, 2021b; Zhao et al. 2023). Specifically, some provided evidence where GPR is detrimental to RE deployment (Abbas et al. 2023; Zhao et al. 2023), whereas others reported neutral or even positive associations (Sweidan 2021a, 2021b). This paper finds that GPR significantly suppresses IRE in developed economies but has no measurable effect in developing economies, thereby reconciling the findings reported in prior studies (Abbas et al. 2023; Sweidan 2021a, 2021b; Zhao et al. 2023).

Secondly, this study contributes to the literature on high-technology trade, global value chains and RE transition. High-technology trade is embedded in global value chains and increasingly governed by Scope 3 disclosure requirements[1] (Gereffi et al. 2005; Hall et al. 2023; Mahieux et al. 2025; Pande 2024), creating cross-border transmission channels through customer–supplier linkages and regulatory spillovers. At the same time, high-technology production is highly electricity-intensive and often carries a substantial carbon footprint when powered by conventional energy sources (Dash 2025; Hu and Chuah 2003). Existing studies focus more on high-technology diffusion and R&D with export-led growth and low-carbon transitions (Chen et al. 2019; Dinh et al. 2021). Evidence on the role of HTE in driving IRE remains limited and largely regional (Bamati and Raoofi 2020; Chen et al. 2019; Dinh et al. 2021). This gap is particularly consequential given widening ESG regulatory heterogeneity and geopolitical fragmentation (Krueger et al. 2024), which may exacerbate the disparities of IRE between developed and developing economies. Our study provides large-sample cross-country evidence that HTE is a significant driver of IRE in developing countries.

Third, this study identifies the differentiated effects of the Paris Agreement and the new mechanisms through which it shapes IRE. As the Paris Agreement has increased pressure on both developed and developing countries to reduce their carbon emissions by, inter alia, investing in RE (Nations 2018; Rogelj et al. 2021; van Soest et al. 2021), the question of how this will be achieved given external contingencies such as geopolitical disruptions and investments remains. Developing and developed countries have different structure, political aspects and risks involved in RE and policies related to climate change (Wang et al. 2022; Zhang and Chiu 2023; Zhao et al. 2023). The study of da Silva et al. (2018) and Rafiq et al. (2014) suggest that such analysis/comparison is important as it can support in providing, inter alia, appropriate RE policies. This comparison on both developed and developing countries alludes to broader notions of social justice within the North–South dialogue, as geopolitical disruptions often exacerbate pre-existing disparities in technological capacity, financial resources and energy security between nations (Escobar 2015; Heffron et al. 2020; van Zyl-Bulitta et al. 2019). With staggered difference-in-differences (DID) models, this paper proves that Paris Agreement reversed the pre-2015 deceleration in IRE and fostered rapid growth, with a significant onset period of 3 years in developing and 4 years in developed countries. We further show that the effect of HTE became pronounced in developing countries after the Paris Agreement, extending Bamati and Raoofi (2020), who find, using data for 10 developed and 15 developing countries over 1990–2015, that HTE promotes RE production only in developed economies. Our findings suggest that the post-Paris policy environment broadened this role, enabling HTE to support IRE in developing economies as well.

Theoretically, this study contributes to SCT by showing that country-level fit is neither static nor uniform, but dynamic, heterogeneous and mutually reinforcing. This finding responds to the long-standing development of, and critiques of, SCT, particularly the view that organisational fit should not be treated as a fixed alignment between structure and environment, but as an evolving and context-dependent process (Donaldson 1987; Shenkar and Ellis 2022; Siggelkow 2002; Volberda et al. 2012; Zajac et al. 2000). In this study, the fit between geopolitical disruptions, HTE specialisation, Paris Agreement commitment and investment in renewable energy varies across developed and developing economies, suggesting that structural adaptation operates through different mechanisms under different national conditions. This paper extends the metafit argument derived from SCT (Volberda et al. 2012), by showing that country-level energy transitions depend on alignment with technical factors (HTE) as well as institutional rules, legitimacy pressures and governance expectations (Paris Agreement). This paper also highlights the importance of international cooperation in reducing GPR and safeguarding RE transition, whereas developing countries should leverage the trade-related channels through which HTEs support IRE.

The remainder of the paper is organised as follows. Section 2 provides an overview of the theoretical foundations and develops the hypotheses. Section 3 describes the data, whereas Section 4 specifies the modelling framework. Section 5 presents empirical evidence. Section 6 concludes the paper by discussing the theoretical and policy implications, limitations and directions for future research.

2 | Theoretical Foundations and Hypotheses

2.1 | Structural Contingency Theory (SCT)

Investment in renewable energy is a necessary component of the transition towards net zero (Khalifa et al. 2022; Vakulchuk et al. 2020). Although the Paris Agreement established a shared commitment to emissions reduction, the pathways towards net zero differ across developed and developing economies (da Silva et al. 2018; Wang et al. 2022; Zhao et al. 2023). These differences raise an important question of how countries adjust their energy structures as the transition unfolds under heterogeneous external conditions.

To address this question, we draw on SCT, which provides a framework that explains how actors seek to achieve fit between internal structures and the external environment (Donaldson 1987; Lawrence and Lorsch 1967; Thompson 2017). Classic SCT identifies (de)centralisation, (in)formalisation and (de)specialisation as key structural dimensions (Dalton et al. 1980; Pugh et al. 1968). Centralisation refers to the extent to which decision-making authority is concentrated at higher organisational levels; formalisation refers to the extent to which organisational behaviour and activities are governed by written rules, procedures and instructions; and specialisation refers to the division of labour, expertise and functional responsibilities. These dimensions are originally developed for firms and organisational units, but they provide a useful starting point for analysing country-level systems if they are carefully translated rather than mechanically applied.

The SCT literature has also evolved beyond a simple static-fit model. Later work argues that fit may be dynamic, because changing contingencies can create misfit and generate pressure for structural adjustment over time (Donaldson 1987; Siggelkow 2002; Zajac et al. 2000). In addition, fit can take different forms, and different structures may perform functionally equivalent roles under similar environmental pressures (Drazin et al. 1985). More recent work further integrates contingency fit and institutional fit by examining how the two interact to influence firm performance (Volberda et al. 2012). This makes SCT particularly suitable for reconsideration in the context of national energy transitions, where countries face changing geopolitical, institutional, technological and economic conditions rather than stable environments.

This study therefore extends SCT from firm-level organisational design to country-level energy-transition systems. Countries are not firms and do not possess a single managerial hierarchy. However, they can be understood as open governance systems whose renewable energy investment depends on the fit between external contingencies and national transition structures. At the country level, centralisation is relevant because the shift from fossil fuel–based systems to RE is often associated with more distributed energy configurations and greater system flexibility (Nadeem et al. 2023). Formalisation is relevant because renewable energy investment depends on policy credibility and regulatory stability to mobilise private capital (Azhgaliyeva et al. 2023; Polzin et al. 2019). Specialisation is relevant because the integration of variable RE requires dedicated regulatory capacities, technical expertise and institutional coordination (IRENA 2020; Verzijlbergh et al. 2017). Taken together, these three dimensions establish the theoretical relevance of SCT for analysing national energy transitions. SCT directs attention not only to whether external pressures matter but also to why their effects may differ across countries and unfold through adjustment over time. The following sections apply this logic to the specific geopolitical, trade-related and institutional conditions examined in this study.

2.2 | Geopolitical Disruptions and IRE

GPR refers to 'the threat, realisation, and escalation of adverse events associated with wars, terrorism, and any tension among states and political factors that affect the peaceful course of international relations' (Caldara and Iacoviell 2022). The effect of GPR on IRE is theoretically contested. The geopolitical disruption that destabilises IRE may simultaneously motivate energy-importing nations to accelerate domestic renewable development (Abbas et al. 2023; Sweidan 2021a, 2021b; Vakulchuk et al. 2020; Zhao et al. 2023). Both mechanisms are empirically documented, and this study poses two competing hypotheses accordingly.

Energy-security concerns provide a central basis for a positive relationship between GPR and IRE. When geopolitical tensions escalate, disruptions to cross-border supply chains can weaken the fit between fossil fuel–dependent energy systems and the external environment, thereby heightening the energy-security risks faced by countries that rely heavily on imported fuels (Bednarski et al. 2025; Khan 2025). Such pressures may induce energy diversification and other adaptive responses (Lee et al. 2024), whereas the expansion of domestically available RE can reduce exposure to GPR associated with imported fossil fuels (Vakulchuk et al. 2020). Consistent evidence from the United States and 10 net oil-importing countries indicates that GPR promotes RE deployment (Sweidan 2021a, 2021b). Therefore, we hypothesise:

H1a. *GPR positively affects the IRE in both developing and developed countries.*

GPR also suppresses IRE by deteriorating the conditions that capital-intensive, long-horizon RE projects require. Three mechanisms drive this suppression. First, geopolitical uncertainty raises the cost of capital and depresses firm-level investment (Caldara and Iacoviell 2022; Carney et al. 2024; Wang et al. 2024), making the long cash flow horizons of RE projects particularly vulnerable to financing cost shocks (Polzin et al. 2015; Schmidt 2014). Second, political instability erodes the regulatory credibility on which private capital depends. The investors of RE projects require policy supports over time horizons that geopolitical shocks can readily disrupt (Fabrizio 2013; Halldén et al. 2025; Polzin et al. 2015, 2019). Third, geopolitical tensions expose the geographically concentrated supply chains of critical minerals (e.g., silicon and copper for solar photovoltaics and lithium for energy storage) to disruption risk that raises project costs and deters IRE (Hendricks and Singhal 2005; Månberger and Johansson 2019). Based on this discussion, we pose the following hypothesis:

H1b. *GPR negatively affects IRE in both developing and developed countries.*

2.3 | HTE and Paris Agreement

HTEs refer to exported products with high R&D intensity (e.g., aerospace, computers, pharmaceuticals, scientific instruments and electrical machinery[2]) and represent one observable component of cross-national production and supply chains. In emerging countries such as Vietnam, HTE baskets are dominated by electronics (e.g., mobile phones and components),[3] supplied to developed downstream markets. However, high-technology activities, particularly semiconductor fabrication and related cleanroom-intensive manufacturing, and AI computing, are highly electricity-intensive and rely on stable power and stringent environmental controls (Dash 2025; Hu and Chuah 2003).

These characteristics make HTE particularly relevant to IRE. Countries with larger HTE sectors require reliable and scalable electricity to sustain production, whereas their integration into global value chains exposes domestic producers to the environmental standards and disclosure requirements of downstream customers. Cross-border production and exporting patterns reflect firms' organisational and location choices that consider the input cost of management, distribution and product-specific R&D (Helpman 1984; Ponte and Gibbon 2005). The GHG Protocol's Scope 3 Standard, for example, extends corporate climate accountability to emissions generated across upstream and downstream supply chains. Chen and Kim (2025) find customer-country disclosure mandates generate measurable adjustments through customer-supplier linkages. In addition, Teplova et al. (2022) find that ESG indicators are positively associated with export intensity among SMEs. From the SCT perspective, these external expectations may reduce the fit between carbon-intensive production structures and the requirements of export markets, creating pressure to adjust production inputs, including energy sourcing.

HTE also reflects the technological and productive capabilities needed to adopt advanced energy technologies. Trade and cross-border production linkages facilitate the diffusion of knowledge and technical expertise across countries (Keller 2004; Taylor et al. 1993). Economies with stronger HTE sectors may therefore be better positioned to support RE technologies (Chen et al. 2019), linking export upgrading to broader low-carbon structural transformation.

Empirical evidence on the relationship between HTE and RE remains limited. Using data for 10 developed and 15 developing countries over 1990–2015, Bamati and Raoofi (2020) find that HTEs promote RE production only in developed economies. Dinh et al. (2021) identify a non-linear association between medium- and high-technology exports and RE consumption in ASEAN economies. Related studies mainly examine technological innovation and carbon-emission reduction rather than the direct relationship between HTE and renewable energy investment (Cheng et al. 2021; Govindan 2023; Mehmood et al. 2024; Su et al. 2022; Wang et al. 2020). Moreover, much of the existing evidence is region-specific or based on data that do not adequately capture the post-Paris Agreement period. Accordingly, we propose the following hypothesis:

H2. *HTE positively affects the IRE in both developing and developed countries.*

The Paris Agreement developed a new global climate governance framework that directly links trade, technology transfer and low-carbon development (Rogelj et al. 2016). Before its ratification, the diffusion of HTE was not adequately aligned with renewable energy investment, and climate-related policy in trade agreements was limited (Vakulchuk et al. 2020). Following the Paris Agreement, GHG Protocol's Scope 3 accounting has increasingly become a mainstream component of ESG reporting (Di Vaio et al. 2024; Hall et al. 2023; Mahieux et al. 2025; Pande 2024) and has reformed international trade rules (Al-Shaer et al. 2024; Teplova et al. 2022). This post-Paris agreement framework strengthens the link between HTE and renewable energy investment by creating both regulatory and market-driven incentives for importing nations to upgrade their energy mix (Govindan 2023).

Based on the previous arguments, we pose the following sub-hypothesis:

H2a. *After the ratification of the Paris Agreement, HTE has a stronger positive effect on IRE in both developing and developed countries.*

3 | Data and Variables

This paper collects data from 100 countries, including 71 developing and 29 developed countries. There are four ASEAN countries in our sample, including Indonesia, the Philippines, Thailand and Vietnam. The sample period covers 15 years from 2007 to 2021. Our dataset is a strongly balanced panel data. The description, descriptive statistics and correlation of the variables are shown in Tables 1–3.

3.1 | Dependent Variable: Investment in Renewable Energy (IRE)

The investment data in RE used in this study consist of the newly installed capacity of solar photovoltaics[4] and wind power, measured in gigawatts (GW), sourced through Bloomberg. We follow the setting of Bersalli et al. (2020) by using physical quantities GW in the measure of IRE. We define the new investment in renewable energy per capita of country i, in year t, as follows:

$$IRE_{i,t} = \frac{CAP_{i,t} - CAP_{i,t-1}}{POP_{i,t}}.$$

$$\forall i = 1, 2, \ldots, 100;\ t = 2007, 2008, \ldots, 2021$$

TABLE 1 | Variables units and sources.

Variable	Description	Units	Sources
IRE	Investment in renewable energy	Newly installed capacity (gigawatts) of solar photovoltaics and wind power per capita	Bloomberg
GPR	Geopolitical risk	Geopolitical Risk Index (GPR) data developed by Caldara and Iacoviell (2022)	https://www.matteoiacoviello.com/gpr.htm
RPA	Ratification of the Paris Agreement	Ratification, acceptance, approval or accession of the Paris agreement, dummy variable	United Nations Treaty Collection
HTE	High-technology exports	Percentage of high-technology exports (current US$) in GDP (current US$)	World Bank
GDP	Gross domestic product	Log value of GDP per capita (current US$)	World Bank
FIT	Feed-in tariffs	Feed-in tariff policy, dummy variable	Renewables Global Status Reports (https://www.ren21.net/) and Climate Scope by Bloomberg NEF (https://www.global-climatescope.org/results/)

TABLE 2 | Descriptive statistics.

Variable	Obs	Mean	Std. dev.	Min	Max
IRE	1322	18.163	33.592	0	288.504
GPR	1322	90.406	9.014	77.984	107.151
RPA	1322	0.366	0.482	0	1
HTE	1322	2.213	3.515	0	29.395
GDP	1322	9.187	1.252	5.771	11.803
FIT	1322	0.557	0.497	0	1

Source: Authors' own work.
Note: Observation number, mean, standardised deviation, min and max value for the variables including IRE (investment in renewable energy), GPR (geopolitical risk), RPA (ratification of the Paris Agreement), HTE (share of high-technology exports), GDP (gross domestic product) and FIT (feed-in tariffs).

where $CAP_{i,t}$ is the total installed capacity of renewable energy at the end of each year; $POP_{i,t}$ is the population in each year.

3.2 | Explanatory Variables

3.2.1 | High-Technology Exports (HTE)

Our model includes the percentage of HTE (current US$) in GDP (current US$). Taking the share of HTE in GDP is a way of averaging values on the economic scale basis, making comparisons across countries. We collect the data on HTE of each country from the World Bank.

We define the share of HTE on GDP of country i, in year t, as follows:

$$HTE_{i,t} = \frac{THTE_{i,t}}{GDP_{i,t}}.$$

$$\forall i = 1, 2, \ \ldots, 100; \ t = 2007, 2008, \ \ldots, 2021$$

where $THTE_{i,t}$ is the total high-technology exports (current US$) in each year; $GDP_{i,t}$ is the gross domestic product (GDP, in current US$) in each year.

3.2.2 | Geopolitical Risk (GPR)

This paper utilises the Geopolitical Risk Index (GPR) data developed by Caldara and Iacoviell (2022) as a proxy of geopolitical disruptions. This index is constructed by analysing the text in about 25 million articles in 10 English newspapers using a dictionary-based method.

3.2.3 | Ratification of Paris Agreement (RPA)

The Paris Agreement was open for signature from April 2016, and the EU and 194 states signed it. Afterward, countries used varied periods to ratify or accede to the agreement, whereas some countries have just ratified it. The dataset is collected from the United Nations Treaty Collection.[5] We collect the year of ratification[6] of the Paris agreement and set it as a dummy variable of country i, in year t, as follows:

TABLE 3 | Matrix of correlations.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
(1) IRE	1.000					
(2) GPR	−0.062	1.000				
(3) RPA	0.201	0.142	1.000			
(4) HTE	0.190	0.001	0.034	1.000		
(5) GDP	0.472	−0.008	0.030	0.299	1.000	
(6) FIT	0.145	0.018	0.078	0.249	0.150	1.000

Source: Authors' own work.

Note: Pairwise Pearson's correlation for the variables, including IRE (investment in renewable energy), GPR (geopolitical risk), RPA (ratification of the Paris Agreement), HTE (share of high-technology exports), GDP (gross domestic product) and FIT (feed-in tariffs).

$$RPA_{i,t} = \begin{cases} 1, & \text{if country } i \text{ has ratified in year } t \\ 0, & \text{if country } i \text{ has not ratified or has withdrawn it in year } t \end{cases}$$

The United States exited the Paris Agreement in 2020 and rejoined in 2021, which is not a normal circumstance. This paper omits these 2 years in the United States as outliers.

3.3 | Control Variables

3.3.1 | Feed-In Tariff (FIT)

FIT is a policy that promises RE producers above-market prices, price certainty and long-term contracts (Nguyen et al. 2023). Polzin et al. (2015) focused on the institutional IRE of OECD countries and tested the effect of distinct policy measures, which proved the effectiveness of FIT. Bersalli et al. (2020) investigated the effect of policies of FI within Europe and Latin America and found a positive significant effect of FIT on IRE in Europe and an insignificant effect in Latin America.

To eliminate the effect of FIT on IRE, we exploited two data sources to collect the data of FIT, including Renewables Global Status Reports[7] and Climate Scope by Bloomberg NEF.[8] We set it as a dummy variable of country i, in year t, as follows:

$$FIT_{i,t} = \begin{cases} 1, & \text{if country } i \text{ has FIT Policy in year } t \\ 0, & \text{if country } i \text{ does not have FIT Policy or has withdrawn it in year } t \end{cases}$$

3.3.2 | Gross Domestic Product (GDP)

This paper also controls the effect of economic growth. Literature shows that economic growth might promote new investment in RE. The work of da Silva et al. (2018) suggested that economic development can aid RE development. Likely, Li et al. (2021) focused on the Chinese market and proved that GDP has a unidirectional positive effect on the IRE. Romano et al. (2017) found a negative effect of GDP on IRE in both developed and developing countries. We collect the data of GDP per capita (current US$) from the World Bank and involved it in our model. Specifically, we normalise the data of GDP per capita by taking its log value.

4 | Model Setting

4.1 | Basic Model

Multiple models, including OLS, fixed-effect panel and two-step GMM-system regression, guarantee our empirical analysis. Our dataset is a short panel with a large cross-sectional dimension (N > T), which makes dynamic panel bias and potential endogeneity important concerns. In dynamic panel settings where the model includes a lagged dependent variable (such as L1.IRE), the use of fixed-effects estimators may lead to dynamic panel bias, also known as Nickell bias (Nickell 1981). To address this, our main specification relies on the two-step system GMM developed by Arellano and Bond (1991) and Blundell and Bond (1998), which is well suited to address these issues by using internal instruments and controlling for unobserved heterogeneity. Nevertheless, for transparency and comparability with previous studies, we report results from OLS and fixed-effects regressions as baseline estimations. This stepwise approach ensures that our findings are not driven by a single estimation technique, and that the robustness of the results can be assessed across alternative models.

To assess the effects of candidate factors on IRE, we specified our model as follows:

$$\begin{aligned} IRE_{i,t} = \alpha + \beta_0 IRE_{i,t-1} + \beta_1 GPR_t + \beta_2 HTE_{i,t} + \beta_3 RPA_{i,t} \\ + \beta_4 FIT_{i,t} + \beta_5 GDP_{i,t} + \varepsilon_{i,t} \end{aligned} \quad (1)$$

where α is the constant, β_1 to β_5 are the coefficients and $\varepsilon_{i,t}$ is the error term. In the fixed-effect panel regression, the constant α is represented in α_i, to estimate the unobserved time-invariant country effect. We estimate the models in different data panels, including the whole sample, subsample of developed countries, subsample of developing countries and subsample of ASEAN countries.

4.2 | DID Model

To examine the effect of the Paris Agreement's ratification, we apply a fixed-effect panel dynamic DID technique (Clarke and Tapia-Schythe 2021). The ratifications of countries ranged from 2016 to 2021, so the event is staggered across countries.

This methodology allows us to estimate dynamic leads and lags around the ratification event (i.e., examining how IRE evolves before and after Paris Agreement ratification), control for both country and time fixed effects, handle staggered adoption across countries and mitigate potential endogeneity concerns (Bertrand et al. 2004). Compared to a simple pre–post or static model, this design provides a more credible causal inference and allows us to test for anticipation effects and dynamic adjustment. The model can be specified as follows:

$$IRE_{i,t} = \alpha + \sum_{j=2}^{J} \gamma_j (Lag\, j)_{i,t} + \sum_{k=2}^{K} \delta_j (Lead\, k)_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \tag{2}$$

where μ_i and λ_t are country and time fixed effect and $\varepsilon_{i,t}$ is the error term. The lags and leads to the event of the Paris Agreement's ratification are defined as follows:

$$(Lag\, J)_{i,t} = \mathbb{1}\left[t \leq Event_i - J\right] \tag{3}$$

$$(Lag\, j)_{i,t} = \mathbb{1}\left[t = Event_i - j\right] \text{ for} \in \{1, \ldots, J-1\}\, j \tag{4}$$

$$(Lead\, k)_{i,t} = \mathbb{1}\left[t = Event_i + k\right] \text{ for } k \in \{1, \ldots, K-1\} \tag{5}$$

$$(Lead\, K)_{i,t} = \mathbb{1}\left[t \geq Event_i + K\right] \tag{6}$$

where the J and K are the maximum year of lead/lag included. The $Event_i$ is the year of Paris Agreement's ratification for country i. This baseline omitted case is the first lag, where $j=1$.

4.3 | Model With Interaction Terms

Since our hypothesis about HTE is highly related to the emergence of ESG in recent years, we focus on the post-effect of the Paris Agreement on the effectiveness of HTE by introducing an interaction term:

$$\begin{aligned} IRE_{i,t} = {} & \alpha + \beta_0 IRE_{i,t-1} + \beta_1 GPR_t + \beta_2 HTE_{i,t} + \beta_3 RPA_{i,t} \\ & + \beta_4 RPA_{i,t} * HTE_{i,t} + \beta_5 FIT_{i,t} + \beta_6 GDP_{i,t} + \varepsilon_{i,t} \end{aligned} \tag{7}$$

As in the basic model, the models with interaction terms are estimated by OLS regression, fixed-effect panel regression and two-step GMM-system regression, using whole samples or different subsamples.

5 | Empirical Results

5.1 | Results of Basic Model

Table 4 reports the regression results for the mixed sample with developed and developing countries. Results are obtained by estimating Equation (1) with OLS, fixed-effect panel and two-step GMM-system methods in the whole sample, where GDP and FIT are control variables. In addition, the multicollinearity test shows max and means VIF values of 1.380 and 1.170. Tables 5 and 6 present the regression results with the same models but use the sample of developed and developing countries separately.

TABLE 4 | Drivers of IRE: overall.

	(1) OLS	(2) Fixed-effect	(3) GMM
L1.IRE	0.756***	0.627***	0.638***
	(0.024)	(0.028)	(0.089)
GPR	−0.163**	−0.19***	−0.085
	(0.07)	(0.07)	(0.059)
RPA	5.348***	6.821***	3.48**
	(1.334)	(1.43)	(1.649)
HTE	0.248	0.153	0.477
	(0.191)	(0.542)	(0.762)
_cons	−21.795***	−34.464	−75.901
	(8.206)	(40.011)	(58.677)
Observations	1207	1207	1207
R-squared	0.6002	0.5902	—
Prob. Arellano–Bond test for AR(2)	—	—	0.373
Prob. Hansen test of overid. restrictions	—	—	0.342
Prob. GMM instruments, Hansen	—	—	0.291
Prob. GMM instruments, Difference	—	—	0.620
Prob. Iv, Hansen	—	—	0.363
Prob. Iv, Difference	—	—	0.263

Source: Authors' own work.
Note: Robust standard errors are in parentheses. Results are obtained by estimating Equation (1) with OLS, fixed-effect panel and two-step GMM-system methods in the whole sample, where GDP and FIT are control variables.
***$p<0.01$.
**$p<0.05$.
*$p<0.1$.

H1a (H1b) predicts that geopolitical risk increases (decreases) new investment in renewable energy in both developed and developing countries. In the full sample, GPR is negative across OLS ($\beta=-0.163$, $p<0.05$) and fixed-effect specifications ($\beta=-0.190$, $p<0.01$) but falls short of significance in the preferred GMM estimator ($\beta=-0.085$, $p>0.1$). The aggregate result, however, masks a sharp divergence across country groups. In developed economies, shown in Table 5, GPR is negative and significant across all three estimators, and the GMM coefficient implies that a one standard deviation increase in GPR (SD = 9.014) is associated with a reduction of 4.37 GW per capita in renewable energy investment, i.e., approximately 24.1% of the full-sample mean. In developing economies, presented in Table 6, GPR is statistically indistinguishable from zero across

TABLE 5 | Drivers of IRE: developed countries.

	(1) OLS	(2) Fixed-effect	(3) GMM
L1.IRE	0.791***	0.682***	0.726***
	(0.04)	(0.045)	(0.088)
GPR	−0.434***	−0.493***	−0.485***
	(0.165)	(0.167)	(0.135)
RPA	10.125***	13.341***	13.11**
	(3.129)	(3.271)	(5.256)
HTE	−0.2	−2.143	−0.199
	(0.426)	(1.53)	(1.529)
_cons	−7.956	10.111	31.252
	(33.65)	(148.992)	(129.114)
Observations	404	404	404
R-squared	0.5732	0.5360	—
Prob. Arellano–Bond test for AR(2)	—	—	0.211
Prob. Hansen test of overid. restrictions	—	—	0.337
Prob. GMM instruments, Hansen	—	—	0.216
Prob. GMM instruments, Difference	—	—	1.000
Prob. Iv, Hansen	—	—	0.237
Prob. Iv, Difference	—	—	1.000

Source: Authors' own work.
Note: Robust standard errors are in parentheses. Results are obtained by estimating Equation (1) with OLS, fixed-effect panel and two-step GMM-system methods in the developed countries subsample, where GDP and FIT are control variables.
***$p<0.01$.
**$p<0.05$.
*$p<0.1$.

TABLE 6 | Drivers of IRE: developing countries.

	(1) OLS	(2) Fixed-effect	(3) GMM
L1.IRE	0.533***	0.392***	0.502**
	(0.036)	(0.04)	(0.196)
GPR	−0.03	−0.041	−0.041
	(0.062)	(0.063)	(0.084)
RPA	4.21***	4.668***	3.943**
	(1.214)	(1.317)	(1.74)
HTE	0.572***	0.951**	1.000**
	(0.198)	(0.452)	(0.495)
_cons	−25.39***	−46.905	−28.517*
	(7.834)	(30.086)	(16.37)
Observations	803	803	803
R-squared	0.3303	0.3009	—
Prob. Arellano–Bond test for AR(2)	—	—	0.131
Prob. Hansen test of overid. restrictions	—	—	0.331
Prob. GMM instruments, Hansen	—	—	0.221
Prob. GMM instruments, Difference	—	—	0.913
Prob. Iv, Hansen	—	—	0.303
Prob. Iv, Difference	—	—	0.710

Source: Authors' own work.
Note: Robust standard errors are in parentheses. Results are obtained by estimating Equation (1) with OLS, fixed-effect panel and two-step GMM-system methods in the developing countries subsample, where GDP and FIT are control variables.
***$p<0.01$.
**$p<0.05$.
*$p<0.1$.

all specifications. The financing structure may help explain the insignificant effect of geopolitical risk in developing economies. RE projects financed primarily through private capital markets are directly exposed to changes in risk premia and financing costs (Caldara and Iacoviell 2022; Carney et al. 2024; Wang et al. 2024). In many developing economies, however, public and development-finance institutions supplement private capital through concessional loans, guarantees, political-risk insurance and other risk-sharing instruments, which might absorb risks that commercial financiers are unwilling to bear (Calcaterra et al. 2024; Isah et al. 2023; Schwerhoff and Sy 2017), and therefore weaken the immediate transmission of geopolitical uncertainty into IRE.

Turning to HTE, the developed-country subsample, presented in Table 5, yields a negative, insignificant coefficient across all estimators ($\beta = -0.199$, $p > 0.1$), providing no support for H2. By contrast, for developing economies, Table 6 shows that the effect of HTE is significantly positive and consistent across the OLS ($\beta = 0.572$, $p < 0.01$), fixed-effect ($\beta = 0.951$, $p < 0.05$) and GMM specification ($\beta = 1.000$, $p < 0.05$). A one standard deviation increase in HTE (SD = 3.515) is associated with an additional 3.515 GW per capita, i.e., 19.4% of the full-sample mean. Our findings stand in contrast to Bamati and Raoofi (2020), who, using data for 10 developed and 15 developing countries over 1990–2015, find that HTE are a significant driver of RE production in developed economies, whereas the relationship is negligible in developing economies. One possible explanation is that our broader and more recent sample captures the deeper integration of developing economies into high-technology global value chains and the stronger post-Paris emphasis on low-carbon production and supply-chain sustainability. We will employ the interaction term model specified in Section 5.4, to further examine whether the Paris Agreement represents a structural break in this relationship.

Tables 4–6 further show that RPA has a positive and significant effect on IRE in both subsamples, with the GMM coefficient substantially larger in developed economies ($\beta = 13.11$, $p < 0.05$) than in developing economies ($\beta = 3.943$, $p < 0.05$), consistent with the greater financial infrastructure and institutional capacity of developed economies to translate ratification commitments into investment action (Besley and Persson 2014; Bortz and Kaltenbrunner 2018; Owusu and Chan 2018). This difference is also consistent with the view that Paris Agreement ratification is translated more rapidly into renewable energy investment where climate-policy frameworks, institutional capacity and green financial markets are more developed (Halldén et al. 2025).

5.2 | DID Results

Figure 2 and Tables A1–A3 show the DID results for the ratification of the Paris Agreement estimated by fixed-effect panel regression within overall, developed and developing countries. It shows the changes in IRE after the event of RPA, not accumulated in the estimation. Figure 2 shows the speed of new investment in renewable energy decreased in recent years before RPA, reflected by the decreasing positive slope. After the RPA, the IRE experienced an increase shaped like a parabola going upwards, which is similar in appearance to exponential growth. The increased IRE is significantly larger than 0 after 3 (4) years for developing (developed) countries. On average, the value of IRE increased by 9.137 GW per capita in 3 years after RPA and by 18.388/28.450 GW per capita in 4/5 years after RPA.

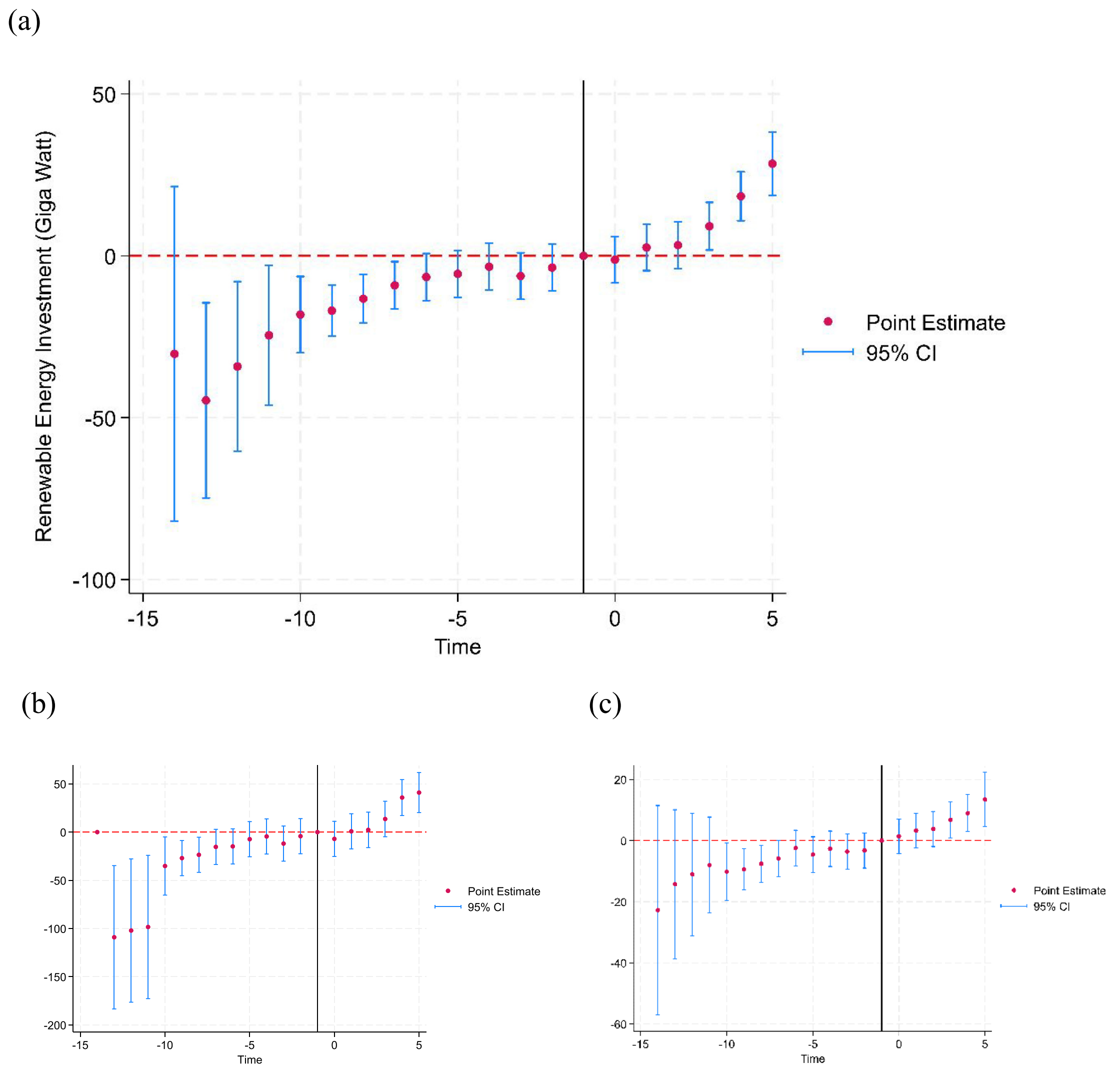

FIGURE 2 | Difference-in-difference for the ratification of Paris Agreement, Overall: (a) Overall, (b) Developed and (c) Developing. *Note:* The x-axis denotes the year, where $t = 0$ is year when country i ratified the Paris Agreement. The results are estimated by Difference-in-Difference models in Equations (2–6), allow for dynamic lags and leads to the event of interest to be estimated, while also controlling for fixed factors (often) by area and time (Clarke and Tapia-Schythe 2021). *Source:* Authors' own work.

In developed countries, the value of IRE increased by 35.807 GW per capita in 4 years after RPA, whereas the increased value of developing countries on average is 40.984 GW per capita in 5 years after RPA. The increase is higher in developed than developing countries, which verifies our hypothesis. Thus, this paper verifies the expansionary effect of the Paris Agreement and concludes that significant onset of impact needs 3 (4) years in developing (developed) countries, respectively.

5.3 | Drivers in ASEAN Countries

Table 7 presents results from ASEAN countries. Limited by the number of observations, only the OLS regression is estimated. The HTE coefficient is positive and significant ($\beta = 0.520$, $p < 0.05$), corroborating the developing-country findings and confirming that HTE activity is associated with IRE within the ASEAN context. GPR is not significant at the ASEAN level, consistent with Table 6. For ASEAN countries, RPA is not a primary driver for the IRE, which is in line with the facts.[9]

5.4 | Results of Model With Interaction Term

To test H2a, Table 8 analyses the interaction between RPA and HTE in the samples of overall, developed and developing countries. Given that RPA is a dummy variable, the interaction term reflects the effect of HTE on IRE only when the countries ratify the Paris Agreement. In line with the previous results, the effect of HTE only exists in developing countries. It is observed that

TABLE 8 | Drivers of IRE with interactions, OLS regression.

	(1) Overall	(2) Developed	(3) Developing
L1.IRE	0.753***	0.791***	0.533***
	(0.024)	(0.04)	(0.036)
GPR	−0.169**	−0.434***	−0.033
	(0.069)	(0.165)	(0.062)
RPA	2.876*	7.269	3.226**
	(1.554)	(4.789)	(1.298)
HTE	−0.3	−0.449	0.045
	(0.261)	(0.531)	(0.318)
RPA*HTE	1.096***	0.646	0.85**
	(0.357)	(0.819)	(0.402)
_cons	−21.521***	−6.855	−24.855***
	(8.178)	(33.695)	(7.821)
Observations	1207	404	803
R-squared	0.603	0.574	0.334

Source: Authors' own work.
Note: Robust standard errors are in parentheses. Results are obtained by estimating Equation (7) with the OLS method, in the whole sample, developed and developing countries subsamples, where GDP and FIT are control variables.
***$p < 0.01$.
**$p < 0.05$.
*$p < 0.1$.

TABLE 7 | Drivers of IRE: ASEAN countries, OLS regression.

	(1)	(2)	(3)	(4)	(5)	(6)
L1.IRE	2.09***	2.069***	2.077***	1.899***	2.09***	1.929***
	(0.184)	(0.184)	(0.192)	(0.185)	(0.187)	(0.2)
GPR		−0.21				−0.281
		(0.187)				(0.179)
RPA			0.943			1.811
			(3.598)			(3.414)
HTE				0.578**		0.52**
				(0.217)		(0.233)
_cons	−0.257	18.825	−0.688	−5.062**	0.005	76.14*
	(1.834)	(17.147)	(2.478)	(2.483)	(7.814)	(41.699)
Observations	40	40	40	40	40	40
R-squared	0.772	0.78	0.773	0.809	0.772	0.833

Source: Authors' own work.
Note: Robust standard errors are in parentheses. Results are obtained by OLS methods in the ASEAN subsample, where GDP and FIT are control variables.
***$p < 0.01$.
**$p < 0.05$.
*$p < 0.1$.

TABLE 9 | Drivers of IRE with interactions: developing countries.

	(1) OLS	(2) Fixed-effect	(3) GMM	(4) OLS	(5) Fixed-effect	(6) GMM	(7) OLS	(8) Fixed-effect	(9) GMM
L1.IRE	0.533***	0.392***	0.503***	0.533***	0.388***	0.485**	0.533***	0.388***	0.487***
	(0.036)	(0.04)	(0.195)	(0.036)	(0.039)	(0.189)	(0.036)	(0.039)	(0.188)
GPR	−0.03	−0.041	−0.039	−0.033	−0.043	−0.039	−0.033	−0.043	−0.049
	(0.062)	(0.063)	(0.088)	(0.062)	(0.063)	(0.082)	(0.062)	(0.063)	(0.087)
HTE	0.572***	0.951**	1.031*				0.045	0.041	−1.529
	(0.198)	(0.452)	(0.583)				(0.318)	(0.604)	(1.614)
RPA	4.21***	4.668***	3.3**	3.177**	3.589***	1.318	3.226**	3.609***	−1.435
	(1.214)	(1.317)	(1.683)	(1.25)	(1.36)	(1.587)	(1.298)	(1.394)	(2.544)
HTE*RPA				0.894***	1.042***	2.242***	0.85**	1.021**	3.987**
				(0.25)	(0.337)	(0.384)	(0.402)	(0.452)	(1.597)
_cons	−25.39***	−46.905	−26.481	−24.82***	−34.162	−28.925**	−24.855***	−34.319	−30.126**
	(7.834)	(30.086)	(16.625)	(7.812)	(30.404)	(14.68)	(7.821)	(30.513)	(14.485)
Observations	803	803	803	803	803	803	803	803	803
R-squared	0.3303	0.3009	—	0.3340	0.3102	—	0.3340	0.3101	—
Prob. Arellano–Bond test for AR(2)	—	—	0.130			0.140			0.148
Prob. Hansen test of overid. restrictions	—	—	0.272			0.429			0.345
Prob. GMM instruments, Hansen	—	—	0.169			0.294			0.228
Prob. GMM instruments, Difference	—	—	0.988			0.951			0.979
Prob. Iv, Hansen	—	—	0.240			0.454			0.404
Prob. Iv, Difference	—	—	0.607			0.188			0.156

Source: Authors' own work.

Note: Robust standard errors are in parentheses. Results are obtained by estimating OLS, fixed-effect panel and two-step GMM-system methods in the developing countries subsample, where GDP and FIT are control variables.

***$p < 0.01$.

**$p < 0.05$.

*$p < 0.1$.

in developing countries, the HTE had no significant effects on IRE before the Paris Agreement was ratified ($\beta = 0.045$, $p > 0.1$), whereas it had positive significant effects on IRE after ratification ($\beta = 0.850$, $p < 0.05$). Hence, we conclude that H2a only holds true for developing countries, whereas developed countries do not offer conclusive results to accept this hypothesis. We further check the robustness by estimating OLS regression, fixed-effect panel regression and two-step GMM-system regression in the subsample of developing countries as shown in Table 9. The GMM estimate in Column (9) of Table 9 implies an additional 3.987 GW per capita per unit increase in HTE following ratification ($\beta = 3.987$, $p < 0.05$).

6 | Implications and Conclusions

6.1 | Theoretical Contributions

This study advances SCT by specifying how fit operates in country-level transition systems. Whereas conventional SCT explains performance through the alignment between organisational structures and external contingencies, our findings show that, at the country level, fit is reflected in how different national structures translate external pressures into investment responses. This translation is contingency-specific, structurally heterogeneous and temporally unfolding. This study advances three strands of the SCT literature. First, it extends the dynamic-fit argument of Zajac et al. (2000) by showing that country-level adjustment to institutional change is not immediate: The effect of Paris Agreement ratification on renewable energy investment emerges only after a 3- to 4-year adjustment period. Second, it develops the multiple-fit arguments of Drazin et al. (1985) by showing that similar external pressures are translated differently across developed and developing economies. Third, it extends the metafit perspective of Volberda et al. (2012) by demonstrating that an institutional change can alter the investment relevance of an existing structural specialisation, as the positive association between HTE and renewable energy investment becomes significant in developing economies only after Paris Agreement ratification.

The HTE findings extend the SCT concept of specialisation from the internal division of labour and expertise to country-level production and export structures. Previous studies have linked high-technology production, technological innovation and export upgrading to RE use, energy efficiency and low-carbon development (Chen et al. 2019; Cheng et al. 2021; Dinh et al. 2021; Govindan 2023; Mehmood et al. 2024). More directly, Bamati and Raoofi (2020), using data for 1990–2015, find that HTE promotes RE production in developed economies but not in developing economies. Our findings reveal a dynamic reversal of this pattern: In the more recent period, HTE are positively associated with renewable energy investment in developing economies, and this effect becomes significant only after Paris Agreement ratification. This suggests that the contribution of export specialisation is not fixed, but changes as the institutional environment evolves. From an SCT perspective, the Paris Agreement altered the conditions under which HTE structures became relevant for domestic renewable energy investment. This interpretation is also consistent with global value-chain research showing that lead firms and downstream markets transmit standards and compliance expectations through supplier relationships (Gereffi et al. 2005; Ponte and Gibbon 2005), and with recent ESG and Scope 3 research indicating that climate accountability increasingly extends across value chains (Chen and Kim 2025; Di Vaio et al. 2024; Hall et al. 2023; Pande 2024).

This study also contributes to the literature on geopolitical risk and renewable energy investment by documenting the heterogeneity across developed and developing economies. Prior studies report mixed evidence on this relationship, as geopolitical risk may increase the strategic appeal of RE through energy-security concerns while also increasing uncertainty and weakening investment conditions (Abbas et al. 2023; Sweidan 2021a, 2021b; Zhao et al. 2023). Our results show that the negative association is concentrated in developed economies, whereas the coefficient is insignificant in developing economies. This pattern is consistent with the view that geopolitical risk may be more disruptive where renewable energy investment is highly exposed to private capital-market conditions, policy credibility and investor confidence. RE projects are capital-intensive, policy-dependent and characterised by long payback periods; they therefore require credible policy commitments, contractual certainty predictable revenue mechanisms, stable supply chains and access to long-term finance (Polzin et al. 2019; Schmidt 2014; Steffen 2020). Geopolitical risk may weaken these conditions by raising financing costs, reducing confidence in policy durability and disrupting renewable technology and critical mineral supply chains (Hendricks and Singhal 2005; Månberger and Johansson 2019; Wang et al. 2024).

In addition, we find that the Paris Agreement is a significant driver of IRE, but its effect materialises only after a 3- or 4-year onset period. This finding adds to studies on RE finance that emphasise the role of credible long-term commitments, regulatory stability and financing conditions in mobilising renewable energy investment (Azhgaliyeva et al. 2023; Fabrizio 2013; Polzin et al. 2015, 2019). It also extends research on the Paris Agreement by showing that ratification is not an immediate investment shock, but a commitment whose investment effect emerges gradually through domestic implementation, financing arrangements and RE project pipelines (Rogelj et al. 2016; Vakulchuk et al. 2020). The post-Paris results further show that the positive association between HTE and IRE becomes significant in developing economies, with a similar pattern observed in the ASEAN sample. It provides a marginal contribution to the literature on trade, global value chains and sustainable transition (Di Vaio et al. 2024; Gereffi et al. 2005; Hall et al. 2023; Ponte and Gibbon 2005) by suggesting that the Paris Agreement may increase the investment relevance of trade-embedded sustainability pressures. This also further extends the SCT institutional-fit argument that organisation-environment alignment may involve formal rules, legitimacy pressures and governance expectations as well as technical fit (Volberda et al. 2012).

6.2 | Managerial and Policy Implications

The transition to net-zero following the Paris Agreement will bring tremendous changes within the economic, environmental and social pillars of sustainability. Both developed and developing countries that work towards net-zero will have the opportunity to grow in terms of wealth, health and climate resilience. If the global community is to achieve net zero by 2050, all countries have to commit to this collective goal and make a genuine effort towards it. The reality is that, given the multitude of dynamic influences at play (e.g., geopolitical tensions and considerations of social justice in calls for all countries to conform uniformly), it is unlikely that a well-coordinated, uniform effort to achieve this goal will emerge. Subject to the limitations noted above, we find that, given the differential impacts faced by developing and developed countries, it is advisable for developed nations to adopt more stringent targets for investment in IRE, which we consider a contributory proxy in the journey to net zero and a response to climate change (Goworek et al. 2018).

Our findings have important policy implications towards the ultimate goal to achieve net-zero by 2050. For developed countries, policymakers should prioritise measures that neutralise the impact of geopolitical risk on renewable investment. Specifically, they should provide regulatory certainty by establishing legally binding long-term renewable targets. Moreover, they should implement supply-chain resilience strategies by diversifying sourcing networks, enhancing regional cooperation and increasing transparency across value chains. As far as developing countries are concerned, policymakers should leverage trade and technology transfer to accelerate renewable energy investment. Explicitly, governments should integrate renewable conditions into trade agreements, promote green procurement and secure finance from multilateral banks and green funds to lower the cost of capital for green investment.

6.3 | Limitations and Future Research

This study is subject to several limitations that offer avenues for future research. First, although the country-level panel design allows this study to compare developed and developing economies, it cannot capture firm- or sector-level variation in how high-technology trade, technology transfer and export-market exposure shape RE adoption. Future research could use firm-level emissions data, supplier–buyer linkages and sectoral energy-use information to examine how trade-embedded sustainability pressures are translated into renewable energy investment decisions.

Second, the analysis does not fully account for regional electricity-market arrangements, such as regional power pools and cross-border grid integration, which may affect how countries respond to geopolitical risk and RE constraints. Future work could examine whether such regional mechanisms mitigate investment risks or accelerate RE deployment.

Finally, the social and distributional effects of export-driven RE growth remain outside the scope of this study. Further research should assess whether RE expansion linked to HTE generates inclusive benefits or creates new inequalities across regions, sectors and communities. Such evidence would help policymakers and practitioners better understand how trade structures and policy instruments can be designed to support a sustainable global transition to net zero by 2050.

Author Contributions

Tianqi Luo: conceptualization, methodology, investigation, writing – original draft, writing – review and editing, data curation, formal analysis. **Konstantinos Baltas:** conceptualization, methodology, formal analysis, investigation, writing – original draft, writing – review and editing, validation. **Ranadeva Jayasekera:** conceptualization, methodology, writing – original draft, writing – review and editing, formal analysis, project administration. **Thanos Papadopoulos:** conceptualization, formal analysis, project administration. **Gazi Salah Uddin:** conceptualization, formal analysis, writing – review and editing, writing – original draft. **Donghyun Park:** conceptualization, validation, formal analysis, data curation.

Endnotes

[1] https://ghgprotocol.org/corporate-value-chain-scope-3-standard.

[2] High-tech exports are defined according to a standard classification (based on Standard International Trade Classification, Revision 4, using a product-level approach originally developed by OECD in collaboration with Eurostat), which aggregates product codes associated with high R&D intensity.

[3] Vietnam provides a representative illustration. The share of high-technology exports in GDP increased markedly from 3.3% in 2009 to 29.4% in 2020. Over the same period, Vietnam's leading export categories consisted of telephones and mobile phones (21% of total exports), textiles (12%), computers and electrical products (12%) and machinery and instruments (6%), with its main export partners being the United States, China, Japan, South Korea and several advanced European economies.

[4] We exclude offshore solar investment because offshore solar photovoltaics generate a tiny proportion of the total capacity. As shown in Bloomberg, only 26 countries have a nonzero record of solar offshore capacity, which accounts for 0.67% of the total capacity in the world.

[5] https://treaties.un.org/Pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-7-d&chapter=27&clang=_en.

[6] The Agreement enters into force on the 30th day after the date on which at least 55 Parties to the Convention accounting in total for at least an estimated 55% of the total global greenhouse gas emissions have deposited their instruments of ratification, acceptance, approval or accession.

[7] https://www.ren21.net/.

[8] https://www.global-climatescope.org/results/.

[9] After the ratification of the Paris Agreement, only Vietnam's IRE rose from 0.273 GW per capita in 2016 to 133.127 GW per capita in 2020 following ratification, whereas Thailand experienced a decrease of IRE from 17.8968 GW per capita in 2016 to 2.1235 GW per capita in 2020. The IRE in Indonesia and the Philippines fluctuated after the RPA.

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Appendix A

TABLE A1 | Difference-in-difference for the ratification of Paris Agreement: fixed-effect reg, overall.

IRE	Coefficient	Std. err.	t	$p>\|t\|$	[95% conf. interval]	
lead14	−30.295	26.323	−1.150	0.250	−81.940	21.350
lead13	−44.665	15.368	−2.910	0.004	−74.815	−14.514
lead12	−34.182	13.370	−2.560	0.011	−60.412	−7.951
lead11	−24.543	11.006	−2.230	0.026	−46.136	−2.950
lead10	−18.150	5.995	−3.030	0.003	−29.912	−6.388
lead9	−16.942	4.020	−4.210	0.000	−24.829	−9.055
lead8	−13.247	3.786	−3.500	0.000	−20.675	−5.819
lead7	−9.117	3.723	−2.450	0.014	−16.422	−1.812
lead6	−6.561	3.703	−1.770	0.077	−13.826	0.704
lead5	−5.575	3.700	−1.510	0.132	−12.834	1.683
lead4	−3.357	3.688	−0.910	0.363	−10.593	3.879
lead3	−6.246	3.657	−1.710	0.088	−13.421	0.930
lead2	−3.624	3.676	−0.990	0.324	−10.837	3.589
lag0	−1.207	3.646	−0.330	0.741	−8.361	5.946
lag1	2.560	3.649	0.700	0.483	−4.599	9.720
lag2	3.290	3.687	0.890	0.372	−3.945	10.524
lag3	9.137	3.752	2.440	0.015	1.776	16.498
lag4	18.388	3.847	4.780	0.000	10.841	25.936
lag5	28.450	4.965	5.730	0.000	18.710	38.191
_cons	20.076	2.548	7.880	0.000	15.076	25.075

Source: Authors' own work.
Note: Results are obtained by estimating Equation (2) with fixed-effect panel in the whole sample.

TABLE A2 | Difference-in-difference for the ratification of Paris Agreement: fixed-effect reg, developed countries.

IRE	Coefficient	Std. err.	*t*	$p > \|t\|$	[95% conf. interval]	
lead13	−109.113	37.801	−2.890	0.004	−183.435	−34.791
lead12	−102.130	37.801	−2.700	0.007	−176.452	−27.808
lead11	−98.447	37.801	−2.600	0.010	−172.769	−24.125
lead10	−35.195	15.348	−2.290	0.022	−65.371	−5.020
lead9	−27.003	9.271	−2.910	0.004	−45.230	−8.775
lead8	−23.573	9.271	−2.540	0.011	−41.800	−5.346
lead7	−15.368	9.271	−1.660	0.098	−33.595	2.860
lead6	−14.839	9.271	−1.600	0.110	−33.066	3.388
lead5	−7.362	9.271	−0.790	0.428	−25.589	10.866
lead4	−4.519	9.271	−0.490	0.626	−22.747	13.708
lead3	−11.934	9.271	−1.290	0.199	−30.161	6.294
lead2	−4.257	9.271	−0.460	0.646	−22.485	13.970
lag0	−7.067	9.271	−0.760	0.446	−25.294	11.160
lag1	0.793	9.271	0.090	0.932	−17.435	19.020
lag2	2.288	9.362	0.240	0.807	−16.118	20.694
lag3	13.579	9.362	1.450	0.148	−4.828	31.985
lag4	35.807	9.479	3.780	0.000	17.169	54.444
lag5	40.984	10.550	3.880	0.000	20.242	61.726
_cons	44.721	6.459	6.920	0.000	32.022	57.420

Source: Authors' own work.
Note: Results are obtained by estimating Equation (2) with fixed-effect panel in the developed countries subsample.

TABLE A3 | Difference-in-difference for the ratification of Paris agreement: fixed-effect reg, developing countries.

IRE	Coefficient	Std. err.	*t*	*p* > |*t*|	[95% conf. interval]	
lead14	−22.728	17.427	−1.300	0.193	−56.936	11.480
lead13	−14.273	12.420	−1.150	0.251	−38.653	10.108
lead12	−11.048	10.207	−1.080	0.279	−31.084	8.988
lead11	−8.021	8.002	−1.000	0.316	−23.728	7.686
lead10	−10.185	4.753	−2.140	0.032	−19.516	−0.854
lead9	−9.420	3.400	−2.770	0.006	−16.094	−2.747
lead8	−7.600	3.069	−2.480	0.013	−13.624	−1.577
lead7	−5.857	2.990	−1.960	0.050	−11.727	0.013
lead6	−2.448	2.966	−0.830	0.409	−8.270	3.375
lead5	−4.557	2.962	−1.540	0.124	−10.371	1.257
lead4	−2.666	2.948	−0.900	0.366	−8.454	3.121
lead3	−3.585	2.913	−1.230	0.219	−9.302	2.132
lead2	−3.228	2.935	−1.100	0.272	−8.989	2.532
lag0	1.413	2.899	0.490	0.626	−4.279	7.104
lag1	3.287	2.903	1.130	0.258	−2.412	8.986
lag2	3.797	2.934	1.290	0.196	−1.963	9.556
lag3	6.792	3.010	2.260	0.024	0.883	12.701
lag4	8.997	3.107	2.900	0.004	2.899	15.096
lag5	13.449	4.534	2.970	0.003	4.549	22.348
_cons	8.038	2.029	3.960	0.000	4.055	12.021

Source: Authors' own work.
Note: Results are obtained by estimating Equation (2) with fixed-effect panel in the developing countries subsample.