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Energy Markets, Geopolitical Risks, and Global Trade: A High-Stakes Tug of War

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ABSTRACT

The ever-evolving energy landscape and rising geopolitical tensions are reshaping global trade like never before. Trade stability faces significant threats, with crude oil, coal, and natural gas prices fluctuating wildly alongside growing geopolitical uncertainties. This study examines the intricate relationship between energy market swings and geopolitical risks, captured through geopolitical risk acts and threats, to uncover their quantile-specific impact on global trade dynamics. Using daily data from December 30, 2016, to January 13, 2025, we apply Multivariate Quantile-on-Quantile Regression and Quantile Regression to dissect how these forces influence trade across different levels. Our findings reveal that crude oil remains the dominant driver of global trade, with its influence intensifying at higher trade quantiles. Meanwhile, coal and natural gas exhibit varying impacts and geopolitical risk acts unexpectedly boost trade in high-quantile scenarios, whereas geopolitical risk threats consistently dampen trade flows. These insights shed light on the dual nature of energy markets and geopolitical risks as catalysts and disruptors of global trade. To navigate these turbulent waters, we advocate for energy diversification, proactive geopolitical risk management, and integrating green energy policies to stabilise trade flows and bolster economic resilience amid growing uncertainties.

JEL Classification: C32, F51, Q40, Q56

1 | Introduction

The relationship between fossil fuels and climate transition investments is central to current policy discussions. The impacts of fossil fuels and climate change are urgent, necessitating attention to the energy systems we construct today. The same fuels driving modern lifestyles must be replaced with cleaner energy in the coming decades. The political landscape complicates this challenge, intertwined with risks, resources, and energy efficiency. This study clarifies the connection between fossil fuels and climate investments, particularly how much is expected to occur in the next 15–20 years. This projection hinges on the actions of leading geological carbon producers in continuing to export and profit from resource investments globally.

We identify three crucial observations. First, oil and natural gas are not evenly distributed globally, while coal resources, particularly in the Asia-Pacific, are more widely available. Consequently, reducing coal usage is slower than oil and gas. Second, there is no consensus on when or how ‘transition investment’ should decelerate or on the trade-offs necessary for reducing carbon emissions effectively. The answers will require political, policy, and strategic analysis. Third, policymakers face a tension between immediate funding needs and long-term climate initiatives. Spending to mitigate future emissions restricts resources available for current reductions (Wang, Guo, et al. 2023; Achakulwisut et al. 2023). The expanding literature on global energy markets, macroeconomics, and geopolitics should enhance discussions on climate strategies and investment dynamics among experts in academia and civil society. It is essential to frame climate challenges and global energy transitions within the broader context of geopolitical and economic changes and to explore how policy goals intersect with competitive markets (Muttitt et al. 2023; Kong et al. 2022; Ansari et al. 2022).

Fossil fuels, including coal, oil, and natural gas, are formed from organic materials and are finite, non-renewable resources. Their unsustainable use raises serious climate change concerns, evidenced by the fact that, as of 2023, fossil fuels continue to dominate the global energy mix, accounting for approximately 81% of total energy consumption. Oil remains the primary energy source, contributing 32% to global consumption, followed by coal at 26% and natural gas at 23% (Visual Capitalist 2023). Despite significant investments in renewable energy, the global reliance on fossil fuels persists, underscoring the challenges in transitioning to cleaner energy sources. While coal and natural gas have lower consumption rates than oil, coal produces more total carbon dioxide emissions.

This reliance on fossil fuels dramatically impacts the global environment, contributing to water, air, and soil pollution alongside the greenhouse effect (Adu et al. 2024; Ozdemir 2023; Voumik et al. 2023). Consequently, investments to shift from high-pollution to lower or zero-emission alternatives are increasingly common. Climate transition investments seek to reduce emissions while committing to combat global warming, as fossil fuels are responsible for around 80% of anthropogenic carbon dioxide emissions, linking climate finance to these energy sources. This highlights the energy politics surrounding fossil fuels and explains regional dependencies on different primary energy sources, positioning them as key candidates for climate change investment strategies. Growing literature and public dialogue reflect policy efforts to manage energy transitions aligned with global climate goals. Furthermore, there is significant scope to explore sustainable development and design policies that harmonise economic growth, international security, and environmental sustainability, considering national resources and energy usage patterns (Min et al. 2022; Gür 2022; Siddik et al. 2021).

The EU Investment Plan classifies climate transition investments as significantly reducing greenhouse gas emissions and enhancing climate resilience. Such investments are crucial for achieving global sustainability and encompass renewable energy, energy efficiency, electric transportation, sustainable urban development, ecosystem services, and circular economy initiatives (Schütze and Stede 2024). Immediate attention to these investments is vital for expediting the path to net zero emissions, requiring industrial restructuring and innovation in supply chains and products. The private sector gains from committing to zero-carbon initiatives, with innovation offering significant benefits.

The EU stresses the need for research and innovation to address greenhouse gas challenges alongside robust regulatory measures to clarify investment landscapes. This includes preventing misleading labels for harmful investments and allowing for a focus on transition investments. The interdependence of climate strategies across financial and environmental spheres means that enhancing resilience can improve economic competitiveness. For instance, in 2019, US businesses faced £226 billion in damages due to climate risks, with significant value threatened by sea-level rise and extreme weather events. As demand for oil and gas declines due to stricter regulations and the rise of electric vehicles, economies reliant on oil may face substantial GDP losses, totalling over £6 trillion through 2040. Major oil and gas firms are responding by investing in clean energy, aided by supportive policy frameworks and collaboration between the public and private sectors (Bressan et al. 2022; Csalódi et al. 2022).

The geopolitical risk is one of the multi-dimensional risks facing the fossil fuel industry as it significantly impacts production, transportation, and downstream projects. Geopolitical risks encompass broader definitions, including political development and international risks like conflicts and resource nationalism. Political instability can provoke wars, and international relations emphasise security, especially concerning conflicts among great powers. As seen in the Persian Gulf's major power struggles, oil and gas supply and demand often become strategic tools within these conflicts. As the energy landscape evolves, resource access remains vital for stable energy supply prices, complicating energy security issues. Therefore, assessing investment opportunities in the fossil fuel value chain requires examining energy geopolitics and security. There is a strong correlation between security demands and sustained fossil fuel supplies.

As of 2023, according to the Carbon Brief 2023 report, fossil fuels—comprising oil, coal, and natural gas—account for approximately 81.5% of global primary energy demand. Regarding oil reserves, OPEC member countries hold about 79.1% of the world's proven crude oil reserves. Regarding natural gas reserves, three countries—Russia, Iran, and Qatar—collectively possess a significant share of the world's proven reserves. As of 2021, according to data from the US Energy Information Administration (EIA), Russia holds the largest share of global natural gas reserves, followed by Iran and Qatar. This reality highlights the risk of energy-related conflicts over oil and gas. In the short to medium term, alternative energy sources struggle to replace the prevalence of traditional fuels. Moreover, simultaneous political tensions in crucial energy zones, like the Russia–Ukraine gas conflict, have cumulative effects, leading to changes in energy policies for the involved nations (Liu et al. 2023; Bricout et al. 2022; Koyamparambath et al. 2022).

Fossil fuels and climate transition investments are deeply interconnected, with fluctuations in fossil fuel markets influencing investment choices in climate alternatives. Geopolitical factors heavily impact the supply and demand for fossil energy, complicating political decisions for states reliant on fossil fuel production. As the climate transition shifts from rhetoric to reality, evaluating feasible investments in an era of climate risks that promise justified returns is crucial. Geopolitics affects the economic climate and drives investments in environmentally friendly projects. Over-reliance on fossil fuels obstructs transition investments as political and climate pressures increase. Investors face a dual response: hedge against geopolitical risks by lobbying and investing in arms and insurance while reinvesting niche profits elsewhere. Although low oil and gas prices may hinder green investments in the short term, they could accelerate the adoption of green technology. Investing in climate-resilient firms is advantageous during geopolitical instability, fostering a stable environment for climate transition investments to tackle trade and climate-related challenges. It is essential to strategically reshape fiscal and institutional frameworks to attract long-term investments in renewable energy, thereby softening future climate change risks. Geopolitics and transition strategy investments are intertwined, with states mindful of their significance in negotiations (Gürsan and de Gooyert 2021; Blondeel et al. 2021; Su et al. 2023).

Given the damaging impacts of fossil fuels on the planet and the volatile geopolitical environment in oil-exporting countries, can climate transition investments be a reasonable choice for investors? If investments in a lower-carbon world are associated with geopolitical risks, the key question becomes how to address these challenges. The rapid transition to a low-carbon economy will lead to an increasingly crowded geopolitical space in the coming decades. Addressing these geopolitical risks is crucial to ensure the resilience of climate transition investments. A robust risk assessment policy incorporating complex geopolitical uncertainties to inform investments, policy-making, and further research becomes vital. This study employs daily data series from December 30, 2016, to January 13, 2025, to examine the impact of fossil fuels on climate transition investments by considering the effects of geopolitical risks. For empirical analysis, we employ the multivariate quantile on quantile regression (MQQR) while we conduct a robustness check on MQQR results using the quantile regression (QR).

This study adds to the growing literature that calls for resilience-building in the global economy. By demonstrating the quantile-specific effects of energy prices and geopolitical risks on trade, it advocates for more granular and adaptive policy responses. For example, countries reliant on crude oil exports must design fiscal buffers to weather low trade intensity periods caused by natural gas price shocks or geopolitical disruptions. Additionally, global institutions like the WTO and IMF could leverage findings like these to promote trade agreements that shield vulnerable economies from energy prices and geopolitical shocks. In addition, governments and international economic and financial institutions should design favourable regulations, rules, principles, and market mechanisms to incentivise sustainable and green investment under geopolitical uncertainty. These strategies can effectively enhance the abilities of climate transition investments to address geopolitical risks.

The remaining sections of the study are as follows: In section 2, we review several existing literatures on the subject to emphasise how significant the topic is to knowledge. Section 3 covers data, data sources, and methodologies adopted for sound, reliable, and robust policy analysis. Section 4 is unique, presenting empirical results mostly in graphical form and discussing findings. We conclude this study and provide workable policy recommendations that are result-driven in Section 5.

2 | Theoretical Framework and Literature Review

2.1 | Theoretical Framework

This study is grounded in several interrelated theoretical and empirical strands that help explain the dynamic interaction between fossil fuel markets, geopolitical risks, and climate transition investments (CTIS), particularly within the context of heightened global uncertainty. The framework integrates theories from resource economics, investment behaviour, climate finance, and geopolitical risk transmission.

2.1.1 | Resource Curse and Energy Dependence Theory

The starting point of this study draws from the resource curse theory, which posits that economies heavily reliant on fossil fuels tend to experience slower economic growth, governance challenges, and structural rigidity due to price volatility and rent-seeking behaviours (Sachs and Warner 2001; Ploeg 2011). In the context of global financial markets, elevated prices and returns from fossil fuel assets—such as crude oil, coal, and natural gas—may divert investment away from sustainable and low-carbon sectors. This phenomenon reflects a broader energy dependence effect, where fossil fuel market dynamics undermine the financial commitment to clean technologies and long-term green transition strategies.

2.1.2 | Portfolio Rebalancing and Substitution Effect

From a portfolio theory standpoint, the substitution effect implies that investors may shift allocations between competing assets depending on relative risks and returns (Markowitz 1991). Climate transition investments (proxied by the S&P World Net Zero 2050 ESG Index) often compete for capital with fossil fuel-based assets. During fossil fuel market booms—usually triggered by geopolitical shocks—investors may rebalance their portfolios in favour of fossil assets, reducing flows into climate transition investments. This reflects both a return-seeking behaviour and a response to shifting risk perceptions.

2.1.3 | Geopolitical Risk Transmission Channels

The influence of geopolitical risks is analysed through the lens of the real options theory and the political risk framework, suggesting that political uncertainty delays investment decisions (Bernanke 1983; Bloom 2009). The study distinguishes between acts-based geopolitical risks (GPRA)—for example, wars, invasions, or attacks—and threats-based risks (GPRT), such as diplomatic tensions or potential conflicts. Acts-based risks typically lead to immediate supply shocks in fossil fuel markets, driving prices and incentivising short-term fossil investment. Conversely, threats-based risks increase uncertainty, which may deter capital inflows into long-horizon green assets due to heightened risk premiums and deferred commitments.

2.1.4 | Climate Finance and Transition Risk Theories

Climate finance theory emphasises the reallocation of global capital toward sustainable and low-carbon pathways in response to physical and transition risks (TCFD 2017). However, transition risks—including policy uncertainty, stranded assets, and fluctuating investor sentiment—can inhibit the growth of climate transition investments. Geopolitical instability exacerbates these risks by undermining the predictability of environmental policy and regulatory frameworks (Battiston et al. 2017). Investors, therefore, may hesitate to allocate capital to ESG-linked indices when geopolitical conflicts signal instability in supply chains, carbon markets, or cross-border cooperation on climate targets.

2.1.5 | Global Trade and Strategic Competition Theory

Finally, this framework draws from strategic trade theory and the international political economy perspective, which argues that geopolitical behaviour shapes global trade patterns and capital flows. Energy-exporting and technology-competing nations often use geopolitical leverage to control strategic resources or technologies, impacting the pace and direction of green transitions (Krugman 1986; Baldwin 1989). In such scenarios, geopolitical risks reconfigure fossil fuel supply chains and shape investor confidence in the geopolitical stability required for climate transition investment to thrive.

2.2 | Literature Review

The global reliance on fossil fuels has profound implications for climate transition investments, particularly when viewed through the lens of current geopolitical risks. As nations grapple with the intertwined challenges of energy security and climate change, the strategic imperatives that underpin fossil fuel reliance become increasingly critical in shaping these investments. The relationship between fossil fuel dependency, geopolitical risk, and sustainable energy policy deserves rigorous examination to inform better strategies to achieve net-zero emissions.

Energy transitions are inherently complex and affected by technological advancements, environmental regulations, and geopolitical dynamics (Acheampong et al. 2023; Bashir et al. 2023). The interplay between geopolitical risks—such as conflicts, trade disputes, and strategic alliances—and energy policies has been posited to have both accelerating and inhibiting effects on climate transition efforts. In particular, studies indicate that geopolitical risks can significantly influence the financial and political landscapes surrounding energy investments (Wang, Zhang, and Li 2024; Wang, Wang, and Li 2024). The uncertainty stemming from these risks often leads to increased caution among investors, potentially stalling critical funding for renewable energy projects (Hoffart et al. 2024; Wang, Wang, and Wang 2023).

Moreover, Chishti et al. (2023) explore how global geopolitical tensions can exacerbate fossil fuel market vulnerabilities, creating a feedback loop that hampers the transition to cleaner energy sources (Hunjra et al. 2024). For instance, events like the Russia-Ukraine conflict have underscored the volatility in fossil fuel supply chains, prompting countries to rethink their energy strategies. This shift highlights how reliance on fossil fuels can undermine the consistency and predictability necessary for renewable investments as nations seek to ensure energy security amidst geopolitical uncertainties (Hille 2023).

The geopolitical risks associated with fossil fuel dependency further complicate adherence to sustainable agreements, as many oil and gas-producing nations face significant pressures to maintain their status in the global energy market. Some scholars suggest that fossil fuel outputs must be curtailed for a timely transition to renewables; however, countries remain reluctant to disrupt existing economic structures reliant on these resources (Goldthau and Youngs 2023). Consequently, rather than facilitating a rapid energy transition, the reliance on fossil fuels often results in delayed responses to climate change, with investments still heavily skewed towards traditional energy sources (Demiralay et al. 2024).

As nations strive to reconcile energy needs with climate commitments, the role of international institutions emerges as pivotal. Gopalakrishnan and Miller (2024) argue that frameworks established by entities like the International Energy Agency can help mitigate geopolitical risks by promoting cooperative approaches to energy transition. Creating policies that align national interests with global sustainability goals is essential, yet the effectiveness of these initiatives often hinges on the geopolitical stability of energy-producing regions.

Another critical dimension of this discourse is the impact of environmental governance and policy on energy transition investments. Bakhsh et al. (2024) highlight the increasing importance of restrictive environmental regulations in shaping investment decisions, particularly in regions dependent on fossil fuel revenues. Diverging policy trajectories across countries can lead to significant disparities in renewable energy advancement, with some nations experiencing rapid growth in renewables. In contrast, others struggle under the weight of fossil fuel dependency (Zhao et al. 2023).

The interplay between fiscal pressures and energy transition initiatives becomes particularly apparent in fragile fossil fuel-producing states, where government revenues are often contingent on fossil fuel extraction. The political economy of such states is defined by rapid shifts in global energy markets and climatic pressures, leading investors to rethink the viability of fossil fuels under new governance paradigms (Shang et al. 2024). Furthermore, the influence of energy transitions on market dynamics cannot be overlooked. Zargar et al. (2024) assert that

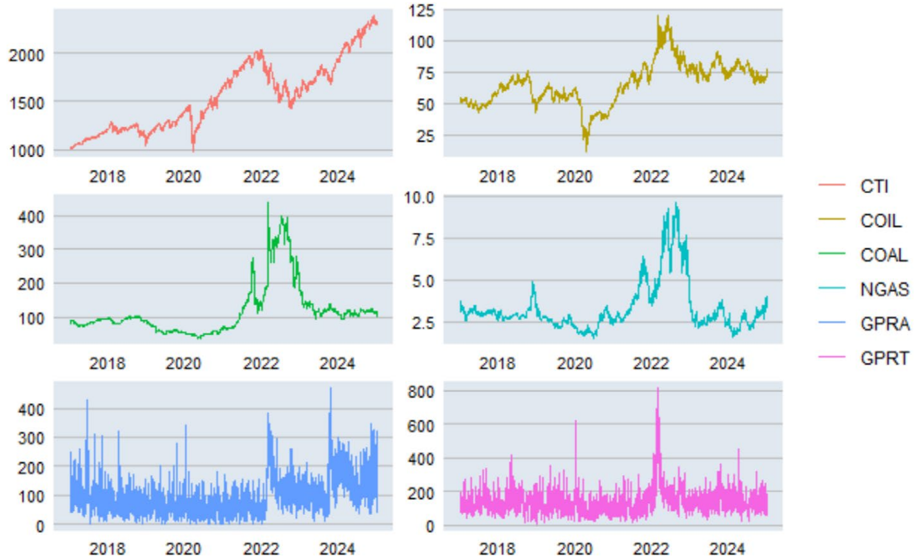

FIGURE 1 | Time trend plots.

as countries pivot toward renewable energy, the interconnectedness between fossil fuel and clean energy markets shapes investor behaviour. Geopolitical risks intensify this complexity; as clean technologies and fossil fuel markets evolve, understanding how these markets correlate becomes crucial for informed investment decisions (Chen et al. 2024).

Investments in renewable energy R&D have begun to reflect the complexities posed by geopolitical risk, as evidenced by the findings of Yuen and Yuen (2024). As countries confront uncertainties regarding their energy futures, public and private investments in sustainable technologies are increasingly viewed through a geopolitical lens. This shift is vital for fostering innovation in energy systems less susceptible to geopolitical fluctuations.

Geopolitical risks and policy uncertainty often act as dual inhibitors of clean energy progress, particularly across the Global South. While geopolitical tensions generate immediate shocks—such as disrupted energy supplies and price volatility—policy uncertainty creates a persistent investment deterrent due to the lack of clear, long-term regulatory frameworks (Yousfi and Bouzgarrou 2024). In low- and middle-income countries, these twin risks can magnify existing infrastructural deficits and fiscal constraints, reducing the credibility of clean energy commitments. Empirical studies have found that policy unpredictability, often rooted in political instability or inconsistent governance, reduces the effectiveness of climate finance mechanisms and leads to lower foreign direct investment flows into renewable sectors (Arndt et al. 2017). For the Global South, mitigating policy uncertainty and geopolitical vulnerability is critical to building investor confidence and ensuring that clean energy transition pathways are inclusive and resilient.

2.3 | Research Gap

Significant gaps remain despite the extensive literature exploring the interconnections between fossil fuel dependency, geopolitical risks, and energy transitions. First, while existing studies highlight the impact of geopolitical risks on renewable energy investments, few provide an intricate, quantitative assessment of how such risks shape investment flows and policy responses across different energy markets. Second, the role of geopolitical risk in determining the speed and direction of energy transitions in developing economies remains underexplored, particularly in regions where fossil fuel revenues constitute a significant component of national income. Finally, there is a lack of empirical research addressing how market linkages between fossil fuels and renewables evolve in response to geopolitical shocks. This study bridges these gaps by providing a comprehensive analysis of the impact of geopolitical risks on climate transition investments, integrating both macroeconomic and policy-oriented perspectives to offer actionable insights for policymakers and investors alike.

3 | Data and Methods

3.1 | Data

This paper uses a daily data series from December 30, 2016, to January 13, 2025, to examine the impact of fossil fuels on climate transition investments by considering the effects of geopolitical risks. In the study, climate transition investments (CTI) are proxied by the S&P World Net Zero 2050 Climate Transition ESG Index from https://www.spglobal.com/en. The S&P World Net Zero 2050 Climate Transition ESG Index is specifically designed to align with the goals of the Paris Agreement, targeting a 1.5°C global warming scenario. It selects and weights equity securities from S&P World based on their alignment with climate transition objectives. The index incorporates metrics such as carbon intensity, decarbonisation trajectory, and climate-related financial disclosures, making it suitable to represent climate transition investments. Moreover, we utilise crude oil futures (COIL), coal futures (COAL), and natural gas futures (NGAS) downloaded from https://www.investing.com for the fossil fuels. Finally, we use act-based and threat-based geopolitical risk indices (GPRA

TABLE 1 | Descriptive statistics.

	Mean	Std. Dev.	Skewness	Kurtosis	Jarque-Bera	ARCH-LM (1)
CTI	1553.727	360.477	0.401	2.067	132.237***	592.102***
COIL	65.835	17.033	0.192	3.317	21.626***	221.551***
COAL	117.076	77.105	2.007	6.579	2526.996***	248.974***
NGAS	3.321	1.504	2.100	7.158	3052.228***	260.182***
GPRA	97.346	65.868	1.292	5.262	1030.526***	24.313***
GPRT	141.626	75.362	2.543	16.932	19219.520***	48.031***

Note: ***$p < 0.01$.

and GPRT, respectively) gathered from https://www.matteoiacoviello.com/gpr.htm to measure geopolitical risks. The evolution of the used data series over the sample period is illustrated in Figure 1.

Table 1 exhibits the descriptive statistics of the CTI, COIL, COAL, NGAS, GPRA, and GPRT series. It is evident from the table that CTI presents the highest average and volatility, whereas NGAS has the lowest daily average and volatility. Moreover, the distribution of all opted series is skewed to the right. CTI has a platykurtic distribution, while other series (COIL, COAL, NGAS, GPRA, and GPRT) have a leptokurtic distribution. The significant Jarque-Bera (Jarque and Bera 1980) and ARCH-LM (Engle 1982) test estimates imply the acceptance of nonnormality and heteroskedasticity for all considered series, respectively. Hence, we continue the analysis by taking the logarithm of all variables.

3.2 | Method

This study investigates the impact of fossil fuels on climate transition investments amid geopolitical risks based on the model as follows:

$$\mathrm{CTI} = f(\mathrm{COIL}, \mathrm{COAL}, \mathrm{NGAS}, \mathrm{GPRA}, \mathrm{GPRT}) \quad (1)$$

CTI represents climate transition investments, COIL represents crude oil futures, COAL indicates coal futures, NGAS signifies natural gas futures, GPRA represents the geopolitical risk acts index, and GPRT represents the geopolitical risk threats index.

While OLS assumes a constant linear relationship and standard quantile regression examines the effect of explanatory variables across quantiles of the dependent variable, MQQR extends this by analysing how specific quantiles of the independent variable affect specific quantiles of the dependent variable. For example, rather than assuming fossil fuel price shocks have a uniform effect on climate transition investments, MQQR allows us to investigate how extreme adverse oil price shocks (e.g., 10th quantile of COIL) influence high-performing green investments (e.g., 90th quantile of CTI). This dual-layered analysis is crucial given the asymmetric and nonlinear dynamics often present during geopolitical instability. This addition better demonstrates the methodological relevance and practical applicability of MQQR in our study.

We employ the MQQR originated by Alola et al. (2023) to test the model given in Equation (1). The MQQR methodology is a modified version of the QQR method proposed by Sim and Zhou (2015), which uses only a 1-factor variable to include more than one-factor variable. For two time series X and Y, where the former is dependent and the latter is the factor variable, the QQR can be modelled as follows:

$$x_t = \Phi_0(\lambda, \psi) + \Phi_1(\lambda, \psi)\left(y_t - y^{\psi}\right) \quad (2)$$

where λ signifies the quantiles of the dependent variable, that is, X, ψ denotes the quantiles of the factor variable (Y), $\Phi_0(\lambda, \psi)$ represents the constant term, and $\Phi_1(\lambda, \psi)$ indicates the slope term, which measures the impact of the Y on the X for all quantile pairs (λ, ψ).

It can be seen from Equation (2) that the QQR methodology captures the impact of the quantiles of a 1-factor variable on the quantiles of a dependent variable. On the other hand, the MQQR analyses the effects of the quantiles of 2 or more factor variables on the quantiles of a dependent variable. Hence, the MQQR shows the impact of each factor variable on the dependent variable by considering the effects of the remaining variables. For n factor variables (Y_1, Y_2, ..., Yn) and one dependent variable (X), the MQQR can be expressed as follows:

$$\begin{aligned} x_t = {} & \Phi_0\left(\lambda, \psi_1, \psi_2, \ldots, \psi_n\right) + \Phi_1\left(\lambda, \psi_1\right)\left(y_{1t} - y_1^{\psi_1}\right) \\ & + \Phi_2\left(\lambda, \psi_2\right)\left(y_{2t} - y_2^{\psi_2}\right) + \ldots + \Phi_n\left(\lambda, \psi_n\right)\left(y_{nt} - y_n^{\psi_n}\right) \end{aligned} \quad (3)$$

where $\psi_1, \psi_2, \ldots, \psi_n$ denotes the quantiles of Y_1, Y_2, ..., Yn, respectively. Furthermore, $\Phi_1\left(\lambda, \psi_1\right)$, $\Phi_2\left(\lambda, \psi_2\right)$, ...,$\Phi_n\left(\lambda, \psi_n\right)$ are the slope coefficients, which demonstrate the impact of the quantiles of Y_1, Y_2, ..., Yn on the quantiles λ of the dependent variable X, respectively, by considering the impact of the quantiles of the remaining factor variables.

This study employs the MQQR for the 19 quantiles from 0.05 to 0.95. Hence, we obtain a 19×19 slope coefficient matrix for each factor variable (i.e., COIL, COAL, NGAS, GPRA, and GPRT). Additionally, different from the extant literature, which employed the MQQR (see, for example, Dong et al. 2024; Özkan et al. 2024; Usman, Ozkan, and Ike 2024; Usman, Ozkan, Koy, and Adebayo 2024; Yu et al. 2024), we estimate the probability values of each slope coefficient for the MQQR via the kernel method. We demonstrate the slope coefficients and respective probabilities of the MQQR estimated for each quantile pair with a heatmap plot for easy understanding.

To check the MQQR results for robustness, this study employs the quantile regression (QR) originated by Koenker and Bassett (1978) and compares the QR estimates with the averaged MQQR estimates as in the studies of Adebayo et al. (2024), Özkan et al. (2024), and Usman et al. (2025). For n factor variables (Y_1, Y_2, ..., Yn) and one dependent variable (X), the QR method can be formulated as follows:

$$Qx(\vartheta \mid y_1, y_2, \ldots, y_n) = k_0(\vartheta) + k_1(\vartheta)y_1 + k_2(\vartheta)y_2 + \ldots + k_n(\vartheta)y_n \tag{4}$$

where $Qx(\vartheta \mid y_1, y_2, \ldots, y_n)$ denotes the conditional quantile of the dependent variable X given Y_1, Y_2, ..., Yn at ϑ-th quantile, $k_0(\vartheta)$ represents the constant term, and $k_1(\vartheta)y_1$, $k_2(\vartheta)y_2$, and $k_n(\vartheta)y_n$ are the slope coefficients, which measure the impact of Y_1, Y_2, ..., Yn on the quantiles of X, respectively.

4 | Empirical Results

The time-varying correlation analysis is a critical preliminary step in the study, providing essential insights for a robust application of the MQQR. These correlations highlight the evolving and potentially nonlinear interactions between fossil fuels, geopolitical risks, and CTIs. Understanding these dynamics is foundational to selecting MQQR as the appropriate methodological framework for capturing nonlinear and distributional effects.

The correlations also help identify asymmetric patterns. The plots indicate that relationships are not uniform across time, with some periods showing stronger positive or negative correlations. This suggests the presence of asymmetric effects, which MQQR can effectively analyse across quantiles. Additionally, by exploring these time-varying correlations, this study confirms the relevance of the chosen variables (COIL, COAL, NGAS, GPRA, and GPRT) in influencing CTIs, affirming their suitability as explanatory factors.

The fluctuating nature of correlations guides the model specification by pointing to the need for a model that accounts for variability across different quantiles of the dependent variable. This reinforces the choice of MQQR as a tool for capturing cross-quantile dependence. Moreover, the correlation patterns provide preliminary evidence of how market conditions and geopolitical risks influence CTIs, which is crucial for tailoring policy interventions and investment strategies in sustainable finance.

The volatility in correlations underscores the importance of examining tail-event dynamics, such as market crashes or geopolitical crises. Conducting this analysis beforehand ensures the study is well-positioned to explore such extreme events systematically with MQQR. The time-varying correlation analysis lays the groundwork for MQQR and ensures the study's methodological choices are data-driven and aligned with its objectives.

Figure 2 provides time-varying correlation plots between CTI and the explanatory variables COIL, COAL, NGAS, and Geopolitical Risk Indices (GPRA and GPRT). These plots reveal key dynamics in the relationships over the study period, highlighting both the strength and direction of the correlations at different time points.

The plot for CTI and COIL shows significant fluctuations, alternating between positive and negative values. This indicates a dynamic and nonlinear relationship, likely influenced by changing market conditions and global energy transitions. On the other hand, the CTI & COAL plot displays relatively stable correlations, with narrower fluctuations compared to other pairs. This may suggest that coal futures have a more consistent relationship with CTI, potentially reflecting its declining role in global energy portfolios.

The CTI and NGAS correlation plots exhibit high volatility, similar to COIL, suggesting that natural gas futures are influenced by transitory shocks and geopolitical factors impacting CTI. The correlation with act-based geopolitical risks (CTI and GPRA) demonstrates substantial variability, reflecting the impact of specific geopolitical events, such as wars and sanctions, on climate transition investments. Lastly, the threats-based geopolitical risk index (CTI & GPRT) shows fluctuations that might represent market anticipations of potential crises, underscoring the forward-looking nature of climate finance.

Table 2 presents the Variance Inflation Factor (VIF) coefficients for the variables used in the estimated model specified in Equation (1). The VIF values provide a diagnostic check for multicollinearity among the explanatory variables, which, if present, could distort the reliability of coefficient estimates. Generally, a VIF value below 5 is considered acceptable and indicative of low multicollinearity.

As shown in the table, all variables—namely COIL, COAL, NGAS, GPRA, and GPRT—record VIF scores well below the conventional threshold. Specifically, COIL has the highest VIF at 4.176, followed by NGAS (3.429) and COAL (3.349), while the geopolitical risk indicators, GPRA and GPRT, show considerably lower VIF values of 1.257 and 1.211, respectively. These results suggest that the model is free from serious multicollinearity concerns, confirming that the included fossil fuel and geopolitical risk variables are statistically independent enough to be used together in the regression framework without inflating standard errors or compromising the interpretability of their estimated effects.

Figure 3 displays the MQQR estimates for the relationship between CTI and its explanatory variables—COIL, COAL, NGAS, and Geopolitical Risk Indices (GPRA and GPRT). The plots illustrate how the quantiles of CTI interact with the quantiles of each explanatory variable, while the statistically significant estimates (at the 5% level) are marked with asterisks (*).

The top-left plot shows a predominantly positive relationship between CTI and COIL across most quantiles. The intensity of the positive association increases at higher quantiles of COIL and CTI, indicating that elevated crude oil prices tend to bolster investments in climate transitions during bullish markets for CTI. This result aligns with studies like Olasehinde-Williams et al. (2023), which suggest that higher oil prices incentivise

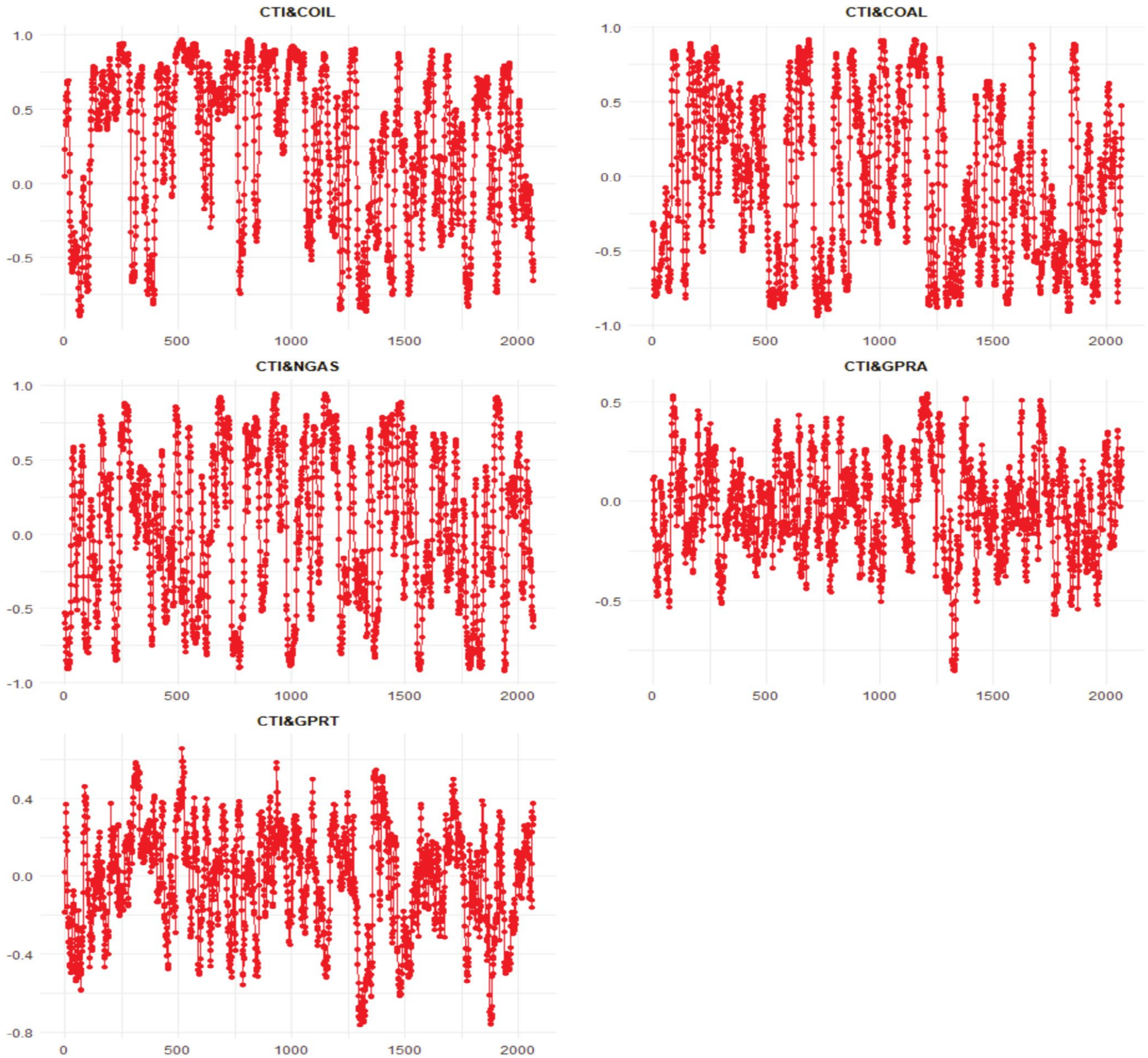

FIGURE 2 | Time-varying correlation plots.

TABLE 2 | VIF coefficients.

Variables	VIF
COIL	4.176
COAL	3.349
NGAS	3.429
GPRA	1.257
GPRT	1.211

clean energy investments by raising the opportunity cost of fossil fuel dependency. However, at lower quantiles of COIL, the relationship weakens, reflecting reduced economic incentives for clean investments during suppressed oil prices.

The top-right plot reveals a mixed pattern in the relationship between CTI and COAL. At lower quantiles of CTI, there is a significant negative correlation with higher quantiles of COAL, suggesting that an increase in coal futures suppresses CTI under unfavourable market conditions for clean energy. Conversely, at higher quantiles of CTI, the relationship becomes marginally positive. This finding is consistent with the narrative that coal prices may influence the financial attractiveness of alternative energy investments under certain economic conditions, as documented in Ben-Salha et al. (2022).

The middle-left plot shows a distinctly asymmetric relationship between CTI and NGAS. At lower quantiles of CTI, there is a significant negative correlation with higher quantiles of NGAS, emphasising that rising natural gas prices deter climate transition investments during market downturns. This finding echoes Etokakpan et al. (2021), which underscores the role of

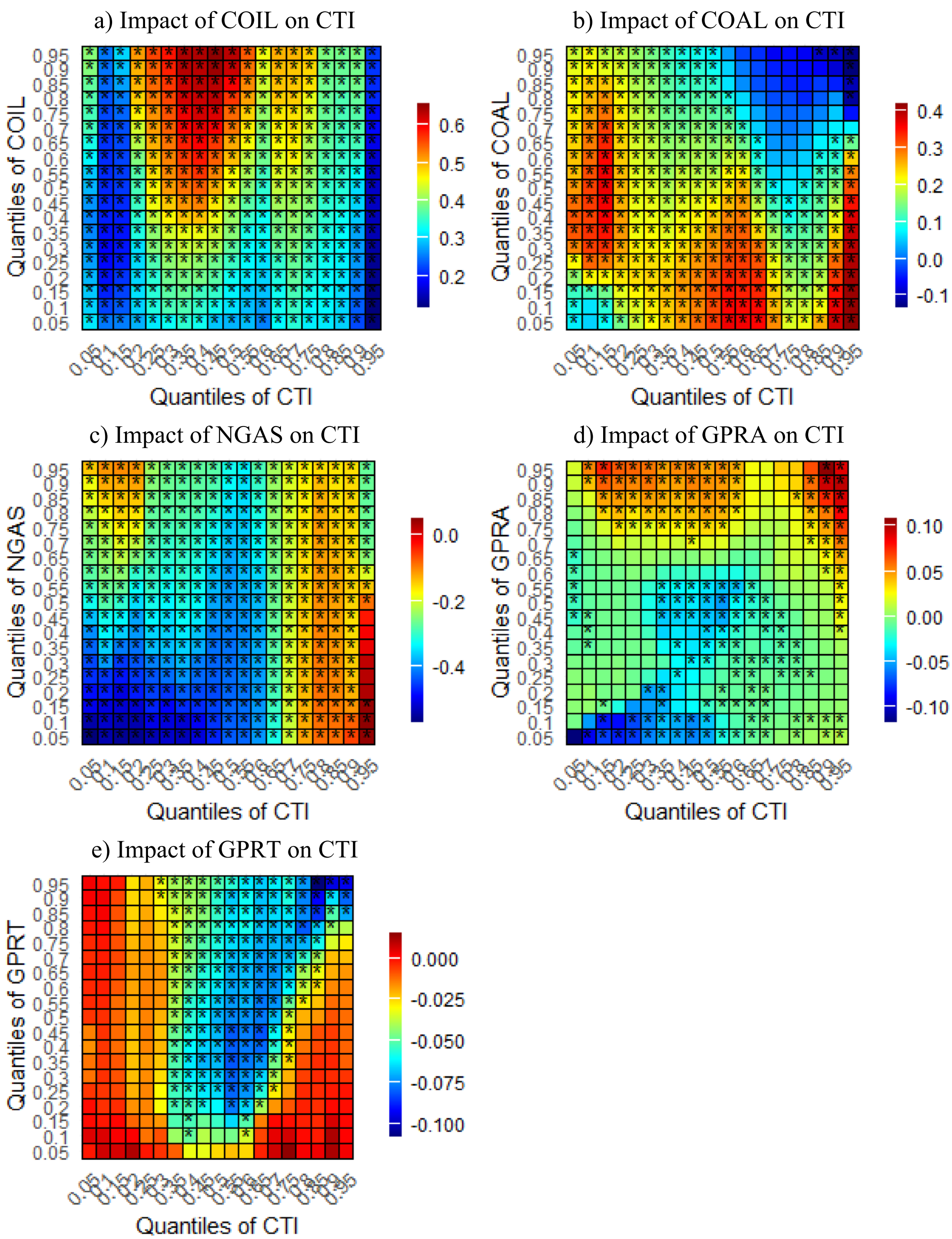

FIGURE 3 | MQQR estimates. The estimates are based on the model CTI = f (COIL, COAL, NGAS, GPRA, GPRT). * Demonstrates significant estimates at the 5% level.

natural gas as a transitional energy source, often competing with renewables. However, at higher quantiles of CTI, the relationship becomes neutral or weakly positive, indicating reduced sensitivity to NGAS during robust clean energy markets.

The middle-right plot highlights a predominantly positive relationship between CTI and GPRA, with stronger correlations observed at higher quantiles of GPRA and CTI. This suggests that act-based geopolitical risks, such as conflicts and sanctions, foster climate transition investments, possibly due to increased urgency for energy security and diversification. These results align with Adebayo et al. (2023), which note that geopolitical tensions often accelerate investments in renewable energy.

The bottom plot shows a clear negative relationship between CTI and GPRT across most quantiles, with significant estimates concentrated in the lower and middle quantiles of CTI. Threat-based geopolitical risks, such as political uncertainty or economic instability, deter investments in climate transitions, particularly during weak clean energy markets. This result is consistent with Adebayo, Akadiri, and Rjoub (2022), highlighting political uncertainty's adverse effects on green investments.

The results of the MQQR estimates underscore the heterogeneity and asymmetry in the relationship between CTI and its explanatory factors. These findings align with the broader literature, emphasising the energy transition dynamics' context-dependent nature. Between COIL and NGAS, the asymmetric effects reinforce the notion that fossil fuel price dynamics shape investment flows into clean energy, as observed in Sadorsky (2012), while the mixed results reflect coal's diminishing role in global

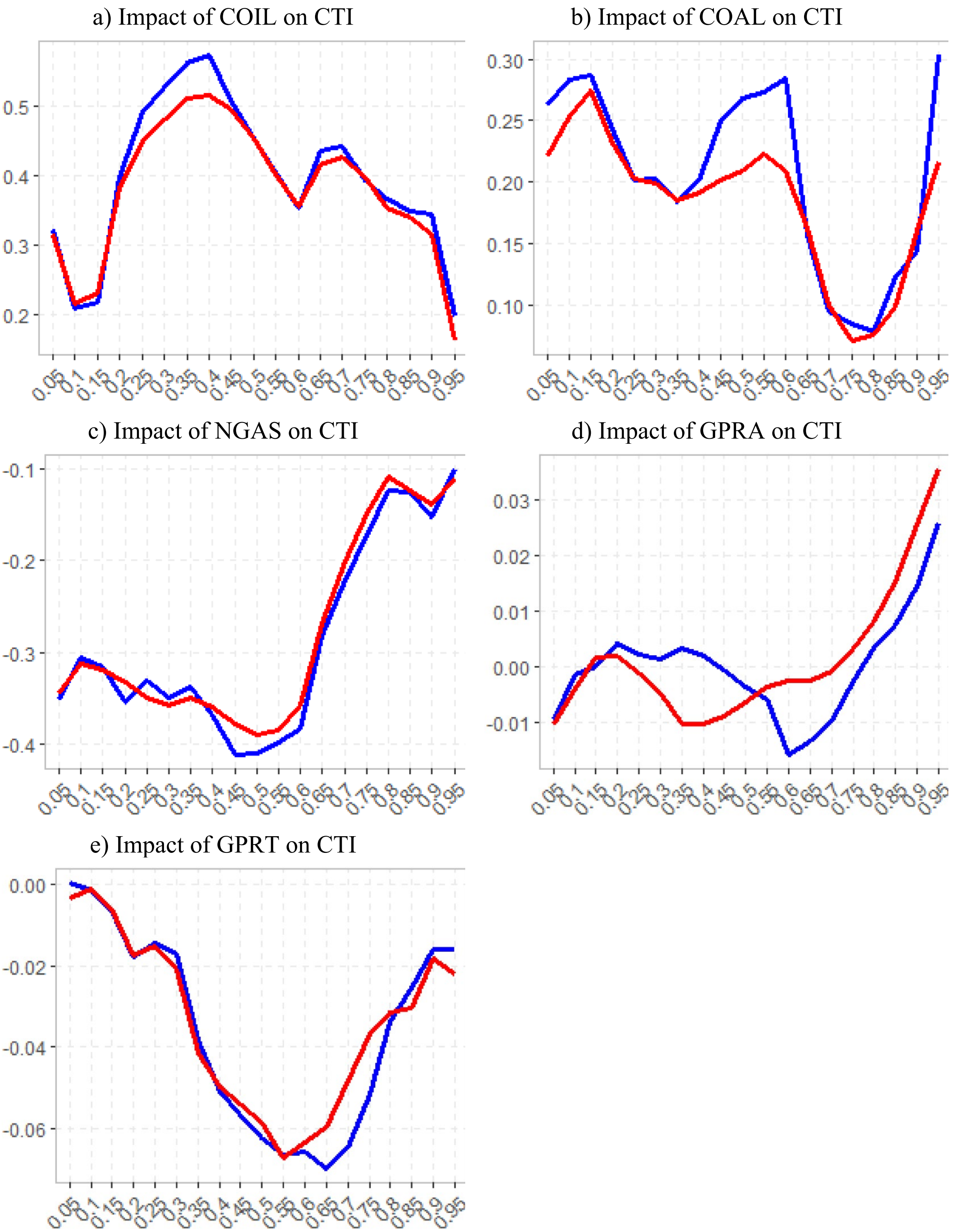

FIGURE 4 | QR (blue) and averaged MQQR (red) estimates. The estimates are based on the model CTI = f (COIL, COAL, NGAS, GPRA, GPRT).

energy portfolios, corroborating studies like Adebayo, Akadiri, Haouas, and Olasehinde-Willams (2022). The GPRA and GPRT, the divergent impacts of acts- and threats-based risks, align with the dual nature of geopolitical events, as documented in Lee et al. (2021).

4.1 | Robustness Check

Figure 4 presents the QR and averaged MQQR estimates for robustness checking. The comparison between the QR (blue) and averaged MQQR (red) estimates demonstrates consistency in the directional patterns and magnitudes, indicating robust results. Notable observations include COIL, where QR and MQQR estimates show a significant positive relationship with CTI across most quantiles. The relationship is more potent at higher quantiles, suggesting that crude oil prices significantly drive trade activity during periods of increased trade intensity. This finding aligns with studies like Dutta et al. (2023), which highlight the influence of oil price dynamics on trade indices.

For COAL, the relationship with CTI reveals varying dynamics. Both QR and MQQR estimates suggest a positive relationship at moderate quantiles, with divergence at the extremes, notably lower quantiles, where MQQR demonstrates slightly higher sensitivity. This indicates that coal's influence on trade is more pronounced in balanced trade scenarios, corroborating Hammoudeh et al.'s (2021) findings on energy transitions.

The estimates for NGAS indicate a significant adverse effect on CTI at lower quantiles, transitioning to a neutral or slightly positive impact at higher quantiles. This suggests that natural gas prices exert pressure on trade when trade intensity is lower but have a diminished effect during periods of high activity. These findings align with Parker et al.'s (2019) observations on the role of natural gas in trade dynamics.

GPRA exhibit a consistent positive relationship with CTI at higher quantiles in both QR and MQQR estimates. This indicates that heightened geopolitical acts amplify trade during periods of significant trade activity, supporting arguments like those of Wang et al. (2021), which highlight the role of geopolitical factors as catalysts in specific contexts. Conversely, GPRT significantly negatively affects CTI across all quantiles, with QR and MQQR aligning closely. This emphasises the detrimental effect of geopolitical tensions on trade, particularly during low-to-moderate trade intensity periods.

The robustness check using QR and MQQR estimates affirms the stability of the relationships explored in this study. The consistent patterns across both methods bolster the reliability of findings, demonstrating that CTI is significantly influenced by crude oil and coal prices. At the same time, natural gas and geopolitical factors exhibit nuanced effects depending on the trade intensity. These results underline the complex interplay of energy markets and geopolitical risks in shaping trade dynamics. This robustness assessment strengthens the study's contribution by validating the employed MQQR approach with complementary QR results. The findings align with prior literature while providing additional quantile-specific insights, showcasing the reliability and applicability of the methods used in the study.

4.2 | Discussion of Findings

This study illuminates the intricate relationship between energy markets, geopolitical risks, and trade, offering critical insights into how these forces shape the global economy. By examining how crude oil, coal, natural gas, geopolitical risk acts, and geopolitical risk threats interact with the Composite Trade Index across different trade intensities, we uncover patterns that hold significant implications for economic resilience and policy formulation.

Our findings confirm that crude oil remains a driving force in global trade, with its impact becoming even more pronounced at higher trade intensities. This reinforces the well-established view (e.g., Kilian and Park 2009) that oil price fluctuations are central to economic activity and trade. The world's continued dependence on crude oil underscores the need for price stability to sustain global trade flows.

Coal and natural gas exhibit distinct but crucial influences. Coal plays a significant role in moderate trade periods, reflecting its lingering relevance in economies gradually transitioning to cleaner energy (Jewell et al. 2019). This suggests that, despite global efforts toward decarbonisation, coal still holds strategic importance in specific energy systems.

In contrast, natural gas exerts an adverse effect at lower trade intensities, signalling its potential to destabilise trade in fragile economic conditions. This volatility may stem from price fluctuations, supply uncertainties, and geopolitical disruptions, making it a less reliable trade facilitator during periods of economic downturn.

Geopolitical events have a profound yet nuanced impact on trade. GPRA—events such as diplomatic negotiations or strategic alliances—can stimulate trade during high-intensity periods, possibly due to shifts in resource allocation or emergency trade measures. However, GPRT—marked by conflicts, sanctions, and military escalations—consistently dampens trade across all levels. This aligns with Caldara and Iacoviello (2022), who highlight how geopolitical tensions disrupt supply chains, increase uncertainty, and deter investment.

Crucially, this study shows that economies do not merely react to geopolitical shocks–they dynamically adapt based on their level of preparedness. Countries with diversified energy sources and resilient trade policies are better equipped to absorb geopolitical shocks, while those heavily dependent on specific resources face disproportionate risks. This highlights the urgent need for multilateral cooperation and robust risk management frameworks to shield global trade from persistent geopolitical volatility.

The heavy reliance on fossil fuels, particularly crude oil, exposes the structural inertia of the global energy system. This study underscores the need for a carefully managed transition as the world moves toward renewable energy. A disorderly shift away from fossil fuels could create economic disruptions, while a slow transition prolongs exposure to energy price volatility (Burke and Csereklyei 2016). Policymakers must strike a balance by investing in renewables while ensuring stable trade flows.

Moreover, geopolitical risks pose a direct challenge to sustainability efforts. The destabilising effects of GPRT on trade could discourage investments in green energy projects, especially in politically unstable regions. This calls for integrated risk-mitigation strategies that align energy transition policies with economic security measures.

This study highlights the need for adaptive and forward-thinking policy responses. Countries reliant on crude oil exports should establish fiscal buffers to weather trade downturns caused by geopolitical shocks or natural gas price fluctuations. Institutions like the WTO and IMF can use these findings at the global level to advocate for trade agreements that protect vulnerable economies from energy price volatility and geopolitical disruptions. By capturing the quantile-specific effects of energy prices and geopolitical risks on trade, this research adds depth to the discourse on economic resilience. It reinforces the idea that a one-size-fits-all approach is inadequate—policies must be dynamic, responsive, and tailored to varying degrees of financial exposure.

5 | Conclusion and Policy Directions

5.1 | Conclusion

This study explores how energy markets and geopolitical risks shape global trade dynamics by analysing the interactions between crude oil, coal, natural gas, geopolitical risk acts (GPRA), and geopolitical risk threats (GPRT) on the Composite Trade Index (CTI). Using daily data from December 30, 2016, to January 13, 2025, we apply advanced statistical techniques—multivariate Quantile-on-Quantile Regression and Quantile Regression—to uncover how these factors influence trade at different intensity levels.

Our findings reveal that energy markets play a crucial role in driving global trade, but their impact is not uniform. Crude oil remains the dominant force, with its influence becoming more pronounced as trade activity increases. Coal has a more noticeable effect in moderate trade scenarios, while natural gas tends to dampen trade at lower levels. Geopolitical risks add another layer of complexity. GPRA, which includes diplomatic manoeuvres and policy shifts, can boost trade during high activity.

In contrast, GPRT—marked by conflicts and heightened tensions—consistently suppresses trade across all levels, reinforcing the destabilising effect of global uncertainty on economic flows. These insights highlight the world economy's vulnerability to energy price swings and geopolitical instability. However, they also underscore the importance of strategic diversification—investing in alternative energy sources and adopting robust policy measures—to build resilience against external shocks. By addressing these challenges proactively, policymakers and businesses can create a more stable and adaptable global trade environment.

5.2 | Policy Directions

Based on the study's findings, several policy recommendations are proposed to enhance the resilience of global trade in the face of volatile energy markets and escalating geopolitical risks. First, accelerating energy diversification strategies is crucial. Given the disproportionate influence of crude oil and the dampening effect of natural gas on trade during periods of low activity, governments should prioritise the transition to renewable and low-carbon energy sources. Such diversification would reduce dependency on fossil fuels and serve as a buffer for trade flows against commodity price shocks. In addition, there is a pressing need to strengthen strategic energy reserves and supply chains. The study underscores the trade vulnerability induced by crude oil shocks, suggesting that net-importing countries, in particular, should invest in strategic petroleum reserves, diversify their sources of energy imports, and enhance regional cooperation to secure uninterrupted trade under market stress.

Furthermore, promoting conflict-responsive trade policies is imperative. Since the Geopolitical Risk Trigger (GPRT) consistently suppresses trade, international institutions such as the WTO and UNCTAD should collaborate with member states to establish flexible trade protocols and geopolitical risk buffers. These may include temporary tariff relaxations and the identification of alternative logistics routes that can be activated during periods of geopolitical conflict. To complement these measures, geopolitical risk intelligence and forecasting must be enhanced. Governments and multinational trade organisations should institutionalise monitoring systems integrating real-time threat assessments, such as GPRT and act-based dynamics (GPRA), into trade policy and investment decisions, enabling timely responses to evolving geopolitical tensions.

Investments should also be directed toward trade-resilient infrastructure. The study indicates that GPRA can stimulate trade during periods of high activity; thus, policymakers should leverage diplomatic channels and stable geopolitical relationships to promote infrastructure projects, such as smart ports, green logistics corridors, and digital customs systems, that maintain trade continuity amid external shocks. Additionally, encouraging the adoption of financial risk management tools among traders is essential. Businesses involved in cross-border trade should be incentivised to utilise hedging instruments such as energy derivatives and geopolitical risk insurance to mitigate their exposure to energy price volatility and geopolitical disruptions.

Lastly, trade agreements must be tailored to reflect the realities of contemporary energy markets. Regional and bilateral trade frameworks should account for the asymmetrical effects of fossil fuels on trade by incorporating energy security clauses and incentives for green energy transitions. These integrated policy actions aim to reduce the fragility of global trade in an increasingly volatile geopolitical and energy landscape, while concurrently supporting a sustainable and secure path for economic growth.

Author Contributions

The authors jointly contributed to and supervised this study.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Peer Review

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