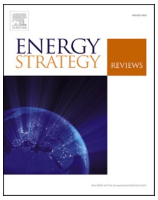
Energy Strategy Reviews 60 (2025) 101786

Contents lists available at ScienceDirect

Energy Strategy Reviews

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



Does financial market stress matter in renewable energy investment? Empirical evidence from BRICS economies

Mohammed Armah [a,*], Ebenezer Bugri Anarfo [a], Emmanuel Numapau Gyamfi [a], Godfred Amewu [b]

[a] *Department of Accounting and Finance, School of Business, Ghana Institute of Management and Public Administration (GIMPA), Achimota, Ghana*
[b] *Department of Finance, School of Business, University of Ghana, Legon, Ghana*

A R T I C L E I N F O

Handling editor: Mark Howells

JEL classification:
B27
C58
D53

Keywords:
Renewable energy
Financial stress
Multivariate quantile-on-quantile
Wavelet coherence
BRICS

A B S T R A C T

Policymakers in BRICS economies face several financial risks in increasing their level of investment in renewable energy. This is because investment in renewable energy is crucial in light of climate change. Although numerous studies have investigated the factors driving renewable energy, little is known about how market stress affects renewable energy. This study explores the critical question that has emerged in the financial literature over the past few decades, namely, the role of financial stress in promoting renewable energy investment. To this end, we employ bivariate and multivariate quantile-on-quantile and wavelet coherence to investigate the effect of financial market stress on renewable energy investment covering the period from 1998 to 2021. Our results show that financial stress adversely affects renewable energy investment during extreme economic downturn. This implies that when market is under stress funding for renewable energy become much harder to secure due to systemic risk. These findings highlight the importance of financial stability for accelerating renewable energy adoption. To sustain renewable growth, BRICS economies need resilient financial policies, such as green financing mechanisms, credit support for renewable firms, and investment-friendly regulations. Ensuring financial stability can help attract long-term capital, making renewable energy a more viable and scalable solution for the future.

1. Introduction

Energy transitions are undoubtedly essential, and global warming is increasingly requiring structural changes in energy systems toward low-carbon energy supply [1]. Renewable energy has emerged as a vital solution for combating global climate change, resulting in a more sustainable and environmentally friendly ecosystem, as well as addressing the energy crisis caused by the depletion of fossil fuels. [2]. The International Agency for Renewable Energy (IARE) reported that renewable energy(RE) is an important policy tool in combating climate change[3]. However, to achieve this important objective, capital investment is required in emerging countries, where energy demand and risk of standard assets are rising[1]. Recently, international initiatives such as the Paris Agreement, United Nations Conference on Climate Change have been launched, with the goal of limiting global temperatures to 1.5DC by 2050[3]. To balance prosperity with environmental issues, policy makers are focussing on promoting renewable energy investment, strengthening innovation as an effective means of internalising harmful environmental impacts. In view of this, policy makers have increased the funding for the invention and dissemination of green technologies and RE [4]. However, in recent years, many unexpected and severe crises have weakened the stability of the country's and world's financial systems and amplified financial stress [5–7]. Due to market uncertainties and instability, the global market faces numerous risks, such as high external borrowing costs, high inflation, and reduced access to market [8]. Under high global uncertainty, the world economy is rife with financial risk which could affect investment such as RE which has been considered as high risk investment([9,10]; He et al., 2019; [11]). In such situations, it is possible to recommend practical measures to mitigate stress that may affect renewable energy if knowledge about how market stress and renewable energy move is empirically tested and documented.

Financial stress(FS) is characterized by instability in the financial market due to shocks from its operations[12], which has a sizable

---

[*] Corresponding author.
E-mail addresses: mohammed.armah@st.gimpa.edu.gh (M. Armah), eanarfo@gimpa.edu.gh (E.B. Anarfo), engyamfi@gimpa.edu.gh (E.N. Gyamfi), gamewu@ug.edu.gh (G. Amewu).

https://doi.org/10.1016/j.esr.2025.101786
Received 1 September 2024; Received in revised form 21 May 2025; Accepted 22 June 2025

impact on the growth and prosperity of countries, regional markets and economic blocs. The unfavourable effects of market stress on the economy cannot be ignored, as they hinder investment, suppress productivity, and weaken the overall stability of the financial sector [13]. Financing RE project in a market that is shrouded by uncertainties and market stress(instability) can hinder the smooth flow inflows of financial resources to meet the needs of RE sectors as noted by Shafiullah et al. [14]. Schwabe et al. [15] pointed out that the financial turmoil that occurred in 2007–2008 distort the flows of equity and debt investment in RE project in USA. Moreover in their work Hofman & Huisman [16] discovered that private equity and venture capital investment in RE investments decline substantially after GFC period. This signal suggests that market stress may significantly affect RE investment. Recognising the symbiotic relationship between financial market stress and economic activities, policymakers must bear the responsibility to implement policies to safeguard financial stability. Meyer & Koefoed [17] state that the successful use of RE in Denmark, Germany and Spain was a result of proper government policies put in place that reduce market stress. Byrnes et al. [18], and Nelson et al. [19] documented that erratic implementation of policies to safeguard financial stability leads to reduction in RE investment in Australia. In Canada White et al. [20] claimed that discontinuation policy uncertainties exacerbate stress that has adverse impact on RE investment in Ontario.

Based on the above literature, it is evident that increased uncertainty can lead to or exacerbate market stress which is likely to influence RE. Therefore, our motivation is fuelled by the lack of evidence on the effect of financial market stress on RE in the 21st century. The role of RE is fundamental to the economy, as RE can contribute significantly to improving economic growth, reducing environmental pollution, and ensuring future generation energy security [21]. RE is becoming an integral part of climate and energy policies. The global nature of energy challenges requires appropriate management and use of RE resources. According to the Energy Union strategy, the European Union (EU) has agreed on targets to ensure clean energy. The share of RE in 2017 was 17.52 % and the target for 2020 is 20 %, indicating that the EU is on track to achieve this goal (European Commission, 2019). These policies are set up to gain market share and convert fossil fuels to RE [22].

Investments in RE are growing rapidly in many developing and emerging economies, especially in BRICS countries[23]. These economic bloc (BRICS) has made significant efforts and commitments to international agreements to mitigate the increased risks of global environmental changes and minimize greenhouse gas emissions. Providing a safe energy supply, increasing energy access and reducing environmental impacts pose a challenges to economic environment. Brazil has set a stage for the production of RE, which relies on hydroelectric power to generate more than 80 % of electricity production[23]. Furthermore, the country is actively investing in wind and solar energy and is hoping to achieve 45 % RE by 2030[23]. Russia has taken steps to promote renewable energy, but most of its energy still comes from fossil fuels. However, it aims to produce 4.5 % of the electricity from RE by 2024 [23]. India's renewable energy sector is growing rapidly and aims to reach 450 GW capacity by 2030. The country has invested heavily in solar energy and has become one of the world's largest producers of RE.[1] China is the world's largest producer of renewable energy and has invested heavily in wind, solar, and hydroelectric power. The country's goal is to produce 50 % RE by 2030 and invest in electric vehicles and energy storage technology. Although South Africa's RE sector is relatively small, the country is planning to produce 18 GW of RE by 2030 [24]. The country has great potential for wind and solar power and is exploring hydroelectric and geothermal energy[24]. The governments of the BRICS countries have made a great commitments to the development of RE over the years. They have implemented policies, regulations, and incentives to encourage investments in RE projects. These initiatives include the introduction of tax benefits, subsidies and RE targets to promote sectoral growth.

Notwithstanding this progress, large-scale financing has been the driving force for RE investment, and since the expected risk is relatively high and the returns are relatively low, most institutional investors are still more likely to participate in fossil fuels than in RE projects[25]. According to IARE investments, achieving Sustainable Development Goals 7 (SDG7) requires an average of $55 billion between 2018 and 2030 to expand access to energy and approximately $700 billion to improve RE[26]. However, financing such a large scale is questionable if there is stress in the financial market. Market vulnerabilities stemming from stress caused by endogenous and exogenous macro-disruptions pose a significant risk to the sustained financing of RE[27]. In fact, literature has shown that the financial market stress has a major impact on global investment through two main channels: financial acceleration and uncertainty mechanisms [28]; [29]. According to Gaies & Chaâbane [27] market stress can interact green investments through these two main channels. Under pressure from climate change, RE projects can benefit from private capital investment, but inadequate funding can significantly undermine this process. Well-informed investment and policy decisions on market vulnerabilities provide greater opportunities for loss protection and allow investment in RE projects. If RE projects are more susceptible to financial uncertainty, investors can be perceived as riskier; thus, they may adopt the 'wait and see' attitude of economic agents hypothesised by Ferrer et al. [30], which implies that investors will hold on to their investment until the market is stable.

Given the pronounced uncertainty in the financial market, the current study delve into the realm of financial stress indicator, which may exhibit variability across diverse market conditions, a crucial aspect for understanding renewable energy investments. The prevailing body of literature primary explore the role of financial development, and various uncertainty in assessing the impact on RE (see Ref. [31–36]; [37–44]. However the existing work tend to overlook how market stress can influence RE. The growing relevance of RE raises the need to evaluate empirically how systemic risk evolves over time and its complex effect on RE investment. Studies that focus on examining the effect FS on RE in the context of BRICS are limited(see Ref. [23,34,45–50]. Tsagkanos et al. [28] provided evidence of the effect of FS on green bonds. Similarly, Gaies & Chaâbane [27] show that FS affects green market in the Euro and American market. However, their study was limited to global financial stress(GFS) and global green markets. In addition the study employs QQR model which is a single-variate-based approach[27]. This technique ignores of other market uncertanities which plays a significant role in market stability[7].The only literature available to the best of our knowledge is the work of Miah et al. [10], who recently examined the effect of market stress on RE in the US using nonparametric and quantile techniques. However, their work remains unclear as to how financial market stress and RE evolve over time as a result of structural changes triggered by major economic events (geopolitics, GFC, EDC, COVID-19). Given the global nature of the financial market for investors, policymakers must have a profound understanding of how RE investments respond to systemic risk over time and market conditions, given that the current global economy is rife with uncertainty. Therefore, by unravelling the intricate relationship between market stress and RE in BRICS economics, our aim is to provide policy makers and investors with information to develop strategies for RE investment in the face of financial imbalance.

The contributions of this study are as follows. First, unlike the existing literature that proxy financial development by liquid liabilities as share of GDP, private credit as share of GDP and proxy stock-based financial development as stock market capitalisation as a percentage of GDP, stock market turnover ratio, and stock market total value traded as a percentage of GDP domestic credit market, can only provide a partial insight into the broader impact of finance on renewable energy. In this study we construct market stress indicator which offer insight into financial market condition. [6,51]. The application stress indicator

---

[1] https://www.investindia.gov.in/sector/renewable-energy.

offer to a better evaluation of overall financial stability in an economy and offers valuable insights into market stress [52]. In this research, we make a meaningful contribution to the literature by constructing a financial stress index and identifying the stress episodes into high or low-stress using the Hodrick-Prescott filter to explore the intricate connection between RE and FS in such an important economic bloc. The distinctiveness of this market bloc lies its wealth of natural resources, such as petroleum and other natural resources they possess [53], the volume of exports, global demand and fluctuations of energy prices, resulting in the strategic importance of these economies [54]. Therefore, our findings underscore the need for policy makers to maintain financial stability to promote the resilience of RE investments in BRICS economies.

Second we use two estimation techniques for analysis: QQR, and wavelet technique. The QQR approach is valuable in assessing the impact of market stress on RE investment. This approach overcomes the constraints of conventional and basic quantile regression, allowing us to examine the impact of both dependent and independent variables across various conditional distributions[55]. The QQR provides a more thorough understanding of the relationships between these variables. It offer a nuanced insights into how market stress influences RE particulary in the extreme condition. In addition to QQR, our research utilises wavelet technique to investigate the underlying connections in time-frequency domain whilst preserving time-specific information[5]. The primary benefit of this method is its ability to uncover potential dynamic relationships between variables across different frequencies over time [56]. Third, beyond financial stress, exogeneous factors such as policy uncertainties, global energy uncertainties, and geopolitical risk plays a critical role in shaping RE investment dynamics. Emipirical shows that policy unpredictability increases risk premia, discouraging long term investment commitment in RE projects[57]. Geopolitical risks arise from conflicts, military tensions, diplomatic relations, and political instability, all of which have direct and indirect effects on financial markets and energy investments. High geopolitical risks lead to uncertainty in financial markets, influencing capital flows, risk premiums, and investor sentiment[58]. High geopolitical increases financial stress by amplifying volatility, capital flight, and sovereign risk perception[59]. On the other hand Energy uncertainties capture fluctuations in energy prices, supply chain disruptions, and volatility in global energy markets. In view of these, our study incorporates these control variables to disentangle the direct and indirect effects of market stress on RE financing and project feasibility. In doing so we extend the bivariate QQR proposed by Sim and Zhou [60] to multivariate quantile-on-quantile (MQQR). The MQQR model, as developed in the works of Alola et al.,; [61]), provides a robust framework for analyzing the time-varying impact of exogenous variables' quantiles on the quantiles of an endogenous variable[62]. Unlike traditional regression models, MQQR effectively captures nonlinearities and asymmetries in the relationship, making it particularly suited for datasets with heterogeneous distributions. Given the non-normal distribution of our study data, conventional mean-based estimators may lead to biased or misleading inferences[63]. The quantile-based methodology of MQQR enhances accuracy and reliability by considering the full distribution of the variables, rather than relying on average effects. Furthermore, this approach provides valuable insights into tail dependencies, revealing whether extreme levels of financial stress (e.g., systemic risk) exert a disproportionate influence on renewable energy investment compared to periods of stability. By applying the MQQR framework, our study identifies the time-varying and distribution-dependent nature of financial stress impact on renewable energy investment across BRICS economies. This technique enables a more granular analysis by assessing how different quantiles of financial stress influence various quantiles of renewable energy investment. Through the MQQR approach, our research fills this gap by providing an analysis and insights that can benefit policymakers, investors, and market participants under different market conditions in the 21st century. Exploring these techniques is imperative to comprehend the dynamic link between the nexus as their driving forces seem to be non-constant, given the structural change of the economy as a result of systemic risk. One of the main research question of this study is to examine the co-movement between RE and RE in time-and frequency domain. To answer this research question we employ wavelet technique which reveals possible dynamics relationship between variables at different frequencies over time [64], [65]. By combining this techniques, our study contributes to the growing body of literature examining the nexus between FS and RE investment. Our findings offer valuable policy and investment implication for market participants working towards sustainable energy transition in emerging economies.

To begin with the outcome of BQQR, and MQQR the results reveal the extreme quantile of market stress have adversely impacted RE in BRICS economies. Of particular significance is the diverse effect observed across different quantile of RE and FS. This observation is consistent with the tenets of the Heterogeneous Market Hypothesis, as put forth by Muller et al. [66]. It emphasises the necessity of taking into consideration the uncertainties in the financial market when investing in RE. Our wavelet results offer valuable insights into temporal dynamics of the relationship between RE and FS. The results of the bivariate and multivariate wavelet coherence explicate a strong correlation between RE and FS in the short term and long term during on the onset of major economic event(GFC, EDC, COVID-19). This observation is consistent with the Noise Trader Hypothesis, as proposed by De Long et al. [67], which suggests that investors base their investment decisions on perceived market trends rather than the intrinsic value of securities fundamentals. Our findings underscore the need for policy makers to maintain financial stability to promote the resilience of RE investments in BRICS economies. Additionally, investors must also consider market conditions and financial stability when investing in RE. Therefore, regulators from several developing economies could learn how systemic risk impacts the investment in renewable energy.

The remainder of this paper is arranged as follows, sections 2-5 section 2 presents the literature review and theoretical framework, section 3 outlines the methodological procedures and data metrics, section 4 presents the empirical findings and discussion and section 5 presents the concluding remarks and policy recommendations.

2. Literature review

2.1. Empirical review

Energy transition has been one of the most discussed issues in academia and policy for many years. Climate change and global warming have recently been recognised as the major environmental problems. The transition from non-renewable to RE is imperative owing to carbon emissions. Investment in RE can help achieve environmental sustainability by limiting carbon emission[68]. However, investment in RE is greatly influenced by the stability of country's financial system. Policy analyst have recommended foreign direct investment(FDI) to promote economic development and the environment[68]. Policymakers in emerging economies are constantly seeking favourable strategic policies to attract foreign direct investment (FDI) to the economy [69]. This is because FDI flows are viewed as alternative sources of external financing and capital accumulation [70]. However FS creates a negative economy situation (Kösedağlı & Önder, 2021).When a country faces FS, it creates a sense of panic and uncertainty that extends beyond its borders [27]. This could lead foreign investors to perceive the negative economic prospects of the affected countries which may lead to the withdrawal of investment[71].

Over the years, scholars focussing on the fields of energy and environmental economics have studied the role of economic variables such as financial development, economic policy uncertainties on green investment (see Ref. [9,11,21,22,33,72–74,74–82]; [83–88]; [89]). The empirical studies suggest that the existing literature usually considers economic and financial uncertainties in RE neglecting macro-level and systemic risks in the development of FS. Despite the fact that uncertainty affect on both real and financial investments, it is widely accepted that FSI offers valuable insights into market stress. The increasing global openness has led to the accelerated integration of BRICS into the global financial markets, resulting in a highly interdependent system of domestic and foreign markets that function together in an organic feedback loop [90,90]. However, this interactive feedback financial market is vulnerable to cross-border and cross-market contagion[90]. Cross market exacerbate market stress leading to financial imbalance[91]. The cross-market integration, interdependencies with other markets been extensively discussed in the literature([92–97]; D. [98]). Recently He et al. [99], examine clean energy and FS in the US and European economies using quantile autoregressive distribution lag. Their findings indicated that financial stress has a negative impact on clean energy in bearish market states in the long run. In their work Tsagkanos et al. [28] investigate FS and green bonds using a Bayesian VAR model. Their findings indicate that FS significantly affects green bonds. Gaies & Chaâbane [27] to investigated the interaction between FI and the green market in the US and EU. The findings reveal that FI has a substantial adverse effect on the green stock market, particularly in the medium-to long term.

In light of above literature, it is evident that FS affects green investment. Although RE investment projects have increased sufficiently, their sustainability is highly dependent on financial stability. If the market is stressed at the macro and micro levels, investment flows will be severely depressed, which may affect RE projects[99]. Athari [34, 100] demonstrated that economic openness and FI have a favourable impact on RE, suggesting that a stable financial system contributes to environmental sustainability, while Nguyen & Dang [101] and Dafermos et al. [102] found that RE can reduce financial stability. Safi et al. [103] recommend that any policy that targets financial stability and RE will significantly reduce carbon emissions. BRICS economies are pivotal in shaping the global energy transition, given their growing energy demand and commitment to sustainability. However, their susceptibility to external shocks and macro-financial imbalance necessitates a deeper examination of how FS influences RE investment. While prior research explores financial development and economic uncertainty on RE, limited attention has been given to market stress on RE investment across BRICS economies. Moreover, recent advances in artificial intelligence (AI) have introduced a transformative dimension to energy finance, enhancing market efficiency, optimizing risk assessment, and mitigating uncertainty in RE investments(see Ref. [104–106].

Given the interconnected nature of the financial market on a global scale, it is crucial for policymakers and investors to grasp the systemic risks associated with each of the BRICS economy in response to changes in investment. The literature on market stress and RE presents a multifaceted view of how macro-financial condition influence the deployment of RE. While existing studies provide valuable insights into broader and financial determinants of RE investment, they exhibit some methodological limitations. First the use of time-invariant econometric approaches fails to capture the dynamic, time-varying nature of FS and its evolving influence on RE markets. Second while the existing studies acknowledge the role of policy uncertainties and geopolitical risks, they do not systematically quantify their interaction with RE in a dynamic, time-varying manner. Third, despite the transformative potential in AI in green finance, the application do not explicitly account for FS indicators or macro-financial uncertainty. To address these gaps, our study employs MQQR and wavelet coherence analysis to capture the asymmetric, and time-frequency interactions between FS and RE investment. This methodological innovation enables us to delineate heterogeneous effects across different market conditions and investment horizons, a perspective largely absent from the existing literature. These contributions position our study as a state-of-the-art, that enhances theoretical and practical understanding of financial market stress and its implications on RE investment in BRICS economies.

3. Methodology

3.1. Quantile-on-quantile regression (QQR)

Followed Armah & Amewu [51] the QQR model developed Sim & Zhou [60] combines of non-parametric steps with the QR model, while the QR model developed by Koenker & Bassett Jr [107] only extends the classical linear regression model by revealing the effects of independent variables on the conditional distributions of dependent variables. In order to assess a complete relationship between the regressand and regressor we use the QQR model which will reveal the effect of various quantiles on different distribution[108]. This is achieved by selecting the number of quantiles of RE (indexed by θ) and estimating the effect that θ quantiles of FS might have on the τ quantile RE. To establish the relationship, between the quantile of FS and the quantile of RE, we constructed a QQR that allows the relationship between RE and FS to vary depending on the distribution of each regressand and regressors. The QQR model is expressed as follows:

$$RE_t = \beta^{\theta}(FS_t) + \varepsilon_t^{\theta} \tag{1}$$

Where RE_t is the renewable at time t, FS is the financial stress index, $\beta^{\theta}(\cdot)$ is an unknown parameter that represent the relationship between RE and FS, θ is the quantile distribution of FS, ε_t^{θ} is the quantile error term.

However the QQR proposed by Sim & Zhou [60] is bivariate in nature and may lead to omitted bias when there are several exogeneous varaibles that could affect the regressand [9,61]. To overcome this issues we employ multivariate quantile-on-quantile regression (MQQR) proposed by Alola et al. [109] to account for the exogeneous factors in the bivariate model. To parameterize this relationship, we assume that the generation of renewable energy follows a distribution of quantiles, and θ^{th} the quantile of RE as a function of FS and other exogenous variables, which is presented as follows;

$$RE_t = \beta^{\theta} + (FS_t) + \sum_n \alpha^{\theta}(FS_t) + \sum_n \alpha^{\theta}(FS_t{*}P_t) + \varepsilon_t^{\theta} \tag{2}$$

Where RE, FS, and P represent renewable energy, financial stress and matrix of n exogenous factors and ε_t^{θ} error term.

Allowing the interaction in equation (2) we have the following:

$$RE_t = \left(\beta^{\theta} + \sum_n \alpha^{\theta}\left(\lambda^{\theta} P_t\right)\right) + FS_t + \sum_n \alpha^{\theta}(P_t) + \varepsilon_t^{\theta} \tag{3}$$

$$RE_t = \beta^{\theta} + (FS_t) + \sum_n \alpha^{\theta}(P_t) + \varepsilon_t^{\theta} \tag{4}$$

In Equation (3) β^{θ} is the unknown parameter moderating the impact of exogeneous factors on RE are not known. To analyse the connection between the regressor and the regressand,we linearize equation (4) by taking a first Taylor expansion of β^{θ} around rr^{τ}, given that $\beta^{\theta}(\cdot)$ is unknown which leads to

$$\beta^{\theta}(fs_t) \approx \beta^{\theta}(fs^{\tau}) + \beta^{\theta'}(fs^{\tau})(fs_t - fs^{\tau}) \tag{5}$$

Where β^{θ} explain the partial derivative $\beta^{\theta}(mp_t)$ that explains the marginal impact. Equation (3) has noteworthy feature where the parameters $\beta^{\theta}(fs^{\tau})$ and $\beta^{\theta'}(fs^{\tau})$ The fs^{τ} τ- quantile of RE, is a function of τ alone and is double indexed in θ and τ. Since $\beta^{\theta}(re^{\tau})$ and $\beta^{\theta'}(fs)^{\tau}$ are the functions of θ and fs^{τ} and since fs^{τ} is the function of τ. This suggest that $\beta^{\theta}(fs^{\tau})$ and $\beta^{\theta'}(re^{\tau})$ are both function of θ and τ. The first order of Taylor function of $\lambda^{\theta}P_t$ reveals that $\lambda^{\theta}(p^{\tau})$ are both function of θ and τ. Consequently equation (8) can rewritten as:

$$\beta^{\theta}(re_t) \approx \beta^{\theta}(\theta, \tau) + \beta_0(\theta, \tau)(fs_t - fs^{\tau}) + \sum_n \alpha^{\theta}(P_t - p^{\tau}) \tag{6}$$

By substituting equation (6) into equation (13) we obtain the following:

In this respect, (*) captures the general structure of dependency between RE and the FS by relying on their respective distributions

$$re_t = \underbrace{\beta_0(\theta,\tau) + \beta_1(\theta,\tau)(re_t - re^\tau) + \sum_n \alpha(\theta)(P_t) + \varepsilon_t^\theta}_{*} \tag{7}$$

It is important to state that (*) also captures the impact of exogenous factors. Hence equation (13) is written as follows:

$$re_t = \underbrace{\beta_0(\theta,\tau) + \beta_1(\theta,\tau)(re_t - re^\tau) + \sum_n \lambda_0[(P_t)(\theta,\tau) + \lambda_1(\theta,\tau)(p_t fs_t - p^\tau fs^\tau)]}_{*}$$

$$\underbrace{+\sum_n \alpha^\theta(\lambda^\theta)(P_t) + \varepsilon_t^\theta}_{*} \tag{8}$$

Finally, we replace fs_t, p_t and fs^τ p^τ by $\widehat{fs}_t$, $\widehat{fs}^\tau$ $\widehat{p}^\tau$, $\widehat{p}_t$ as follows:

$$\min_{b_0, b_1, \lambda_0, \lambda_1,} \sum_{t=1}^{n} \rho\theta \left[re_t - b_1 - b_0(\widehat{fs}_t - fs^\tau) - \sum_n \lambda_0 + \lambda_1(\,\widehat{p}_t\widehat{fs}_t - \widehat{p}^\tau fs^\tau) + \sum_n \alpha^\theta(\lambda^\theta)(P_t) \right] - K\left(\frac{F_n(\widehat{fs}) - \tau}{h}\right) \tag{9}$$

Where $\widehat{fs}_t, \widehat{fs}^\tau$, $\widehat{p_t fs_t}$, $\widehat{p^\tau fs^\tau}$ are the estimated values of fs_t, fs^τ, $p_t fs_t$ and $\rho\theta$. The quantile loss $\rho\theta$ is defined as $\rho\theta = \mu(\theta - 1(<0)), i$ is the function. In our case we are concerned with the effect of the τ -quantile of RE, so we a Gaussian kernel $K(\cdot)$ whereas h represents bandwidth. The goal of the kernel function is to provide accurate information on the target target point and determine the size and complexity of the estimated results. These weights associated with the kernel function are inversely proportional to the distribution of functions, and this relationship is described as follows.

$$F_n(\widehat{fs}) = \frac{1}{n}\sum_{k=1}^{n} I(\widehat{fs}_k < \widehat{fs}_t) \tag{10}$$

We fellow the bandwidth selection approach suggested by Sim & Zhou [60] to minimize potential biases in our results, particularly in instances where the bandwidth is significant and when it is large and when it is smaller and exhibits higher variance. In conducting our empirical analysis, we selected a plug-in bandwidth of h = 0.05 to 0.95.

3.2. Wavelet coherence

The impact of FS on the conditional RE is carried using QQR. However, it is plausible that these nexus might exhibit a time-varying effect. To unravel this temporary variability, we employ both bivariate and multivariate wavelet coherences. Wavelet analysis evaluates the spectrum properties of time series as a function of time and shows how different periodic elements of time series change over time[110]. Unlike Fourier that transforms time series into sinusoidal components of different frequencies and time-infinite durations, wavelet transforms expands time series into a function called the Mother Wavelet, which has a limited spectrum band and a limited time-infinite duration[111].

3.3. Continuous wavelet transform

Following Aguiar-Conraria et al. [110] and Aguiar-Conraria et al. [112], we start with mother wavelet ψ, a family $\psi_{s,\tau}$ of "wavelet daughters" is obtained by scaling ψ and s translated by τ:

$$\psi_{\tau\,s}(t) = \sqrt{s}^{-1}\psi\left(\frac{t-\tau}{s}\right), \Psi(\cdot) \in L^2(R) \tag{11}$$

Where $\sqrt{s}^{-1}$ represent the normalization factor, which ensure that the variance of wavelet $\|\Psi_{i,s}\|^2 = 1$. τ represents the exact location of the wavelet, s represents the scale dilation of the of the wavelet which shows how the wavelet is dilate. Given the time series $x(t)$ based on a selected mother wavelet can be discomposed as follow:

$$W_{x\,(\tau,s)} = \int_{-\infty}^{+\infty} x(t)s^{-1/2}\psi\left(\frac{t-\tau}{s}\right)dt \tag{12}$$

The importance of admissibility conditions (6) stems from the guarantee that $x(t)$ can be recovered from the wavelet transformation [111]

$$x(t) = \frac{1}{c_\psi}\int_{-\infty}^{+\infty}\left[\int_0^{+\infty} W_x(\tau,s)\psi_{\tau,s}(t)du\right]\frac{ds}{s^2}, \tag{13}$$

From Equation (3) The power spectrum can be calcualated by specifying the variance, as describe below follows;

$$\|x\|^2 = \frac{1}{c_\psi}\int_{-\infty}^{+\infty}\left[\|W_x(\tau,s)\|^2 du\right]\frac{ds}{s^2}, s > 0 \tag{14}$$

Equation (14) defines the wavelet power to measure the variability of time and frequency series as $|W_{x\,(\tau,s)}|^2$. Due complex nature of wavelet transform, W_x may also be complex hence the transform is divided into real $\Re(W_x)$ imaginary parts $\mathcal{I}(W_x)$, amplitude $|W_x|$ and the phase $\varnothing_{xy}(\tau,s) = tan^{-1}\left(\frac{\Re(W_x)}{\mathcal{I}(W_x)}\right)$. The real $\Re(W_x)$ imaginary parts $\mathcal{I}(W_x)$, undefined hence in order to separate phase difference and amplitude it is important to select the wavelet function $\psi(t)$ such that $\psi(f) = 0$ for $(f < 0)$. If the time series $x(t)$ is real the variant of the reconstruction in which the parameter s is restricted to positive value under the following condition:

$$x(t) = \frac{2}{c_\psi}\int_{-\infty}^{+\infty}\left[\int_0^{+\infty} \mathbb{R}\left(W_x(\tau,s)\psi_{\tau,s}(t)d\tau\right]\frac{ds}{s^2} \tag{15}$$

And it can also be written as

$$\|x\|^2 = \frac{2}{c_\psi}\int_{-\infty}^{+\infty}\left[\int_0^{+\infty} \left|\left(W_x\tau,s)\right|^2(t)d\tau\right]\frac{ds}{s^2} \tag{16}$$

There are different types of wavelet function with different features such as Morlet, Haar, and Daubechies [111,113]. However since the coefficient of wavelet $W_x s,\tau$ that combine the information on the time series $x(t)$ and wavelet function $\psi(t)$, we employ Morlet wavelet which is define as $\psi_o(\eta) = \pi^{-\frac{1}{4}}\left(e^{i\omega_0\eta}e^{-\eta^{\frac{2}{2}}}\right)e^{\frac{t^2}{2}}$. Here $e^{-\eta^{\frac{2}{2}}}$, we introduce to pledge the fulfilment of the admissibility condition. This become negligible if $\eta \geq 5$ and is written as $\psi_o(\eta) = \pi^{-\frac{1}{4}}\,e^{i\omega_0\eta}e^{\frac{t^2}{2}}$ with support of $(0,\infty)$ and $(0,-\infty)$ and written as: $\psi_o(\eta) = \pi^{-\frac{1}{4}}\,\sqrt{2e}\;\frac{-1}{2}(2\,\pi f - \eta)^2$ been the centre of the point $(0, \frac{\eta}{2})$ of the frequency $\eta = 6$ with the frequency center as of $\mu f = 6/2\pi \approx 1$.The relationship between the frequency and scale is depicted as $f = \mu f/s \approx 1/s$. Here the time variance is $\sigma_t = 1/\sqrt{2}$ while the frequency variance $\sigma_t = 1/\left(2\pi\sqrt{2}\right)$.

The background spectrum of red noise is used to define a null hypothesis in significance tests of the peaks of the wavelet spectrum. This is calculated using Monte Carlo simulation [114]. The wavelet power spectrum for the time series is defined as follows;

$$D\left(\frac{W_y^x(s)^2}{\delta_x^2} < p\right) = \frac{1}{2}p_f x_v^2 \tag{17}$$

Where the wavelet scale s corresponds to the Fourier frequency($s \approx 1/f$). δ_x^2 represent the variance of the corresponding variable and the real wavelet has $v = 1$. Following Rua & Nunes [115], we define the cross-wavelet transform of the time series $s(t)$ as follows; $W_p^{xy}(s) = W_p^x(s)W_p^{y^*}(s)$. Where the wavelet scale s corresponds to the Fourier frequency($s \approx 1/f$). δ_x^2 represent the variance of the corresponding variable and the real wavelet has $v = 1$. Wavelet coherence, which is the square of the absolute value of a wavelet cross-spectrum normalized to the single spectrum of wavelet power Torrence & Compo [116]. It is defined as the following:

$$R^2(\tau, s) = \frac{\left|S\left(s^{-1}W_{xy}(\tau, s)\right)\right|^2}{S\left(s^{-1}\left|W_x(\tau, s)\right|^2\right) S\left(s^{-1}\left|W_y(\tau, s)\right|^2\right.} \tag{18}$$

where S is the smooth operator. $R^2(\tau, s)$ present the square of correlation localized in terms of time and frequency. $W_{xy}(\tau, s)$ present the cross wavelet transform of the two-time series.

We compute the phase difference through Monte Carlo simulation as follows:

$$\varnothing_{xy}(\tau, s) = tan^{-1}\left(\frac{\boldsymbol{I}(S(s^{-1}W^{xy}(i, s)))}{\mathbb{R}(S(s^{-1}W^{xy}(i, s)))}\right) \varnothing_{xy} \in [-\pi, \pi] \tag{19}$$

where $\boldsymbol{I}$ and $\mathbb{R}$ are, respectively, the imaginary and real parts of the smoothed coherence wavelet transform. Wavelet coherence is defined by the dimensional phase pattern, and the varying phase patterns are distinguished by using dimensional arrows. To comprehend the phase difference we need to define the concept of phase pattern between the time series $x(t)$ given that $\varnothing_{xy}(\tau, s) = -\varnothing_{xy}(\tau, s)$ and $-\ \pi \leq \varnothing_{xy}(\tau,s) \leq \pi$. The phase difference can be divided into four. The first phase is $\varnothing_{xy}(\tau, s) \in \left(0, \frac{\pi}{2}\right)$, which implies that FS lead RE. This means that FS has some significant predictive information about FE. The second is $\varnothing_{xy}(\tau, s) \in \left(-\frac{\pi}{2}, 0\right)$ RE lead FS meaning that FE has significant predictive information about FS. In the first two phase difference suggest the both variables are in-phase meaning that they move in the same direction. In the third and fourth phase difference namely $\varnothing_{xy}(\tau, s) \in \left(\pi, \frac{\pi}{2}\right)$ and $\varnothing_{xy}(\tau, s) \in \left(-\pi, -\frac{\pi}{2}\right)$, both variables are out-of-phase meaning that they move in opposite direction. The lead/lag information on the phase difference $\varnothing_{xy}(\tau, s) \in \left(\pi, \frac{\pi}{2}\right)$ $\varnothing_{xy}(\tau,s) \in \left(-\pi, -\frac{\pi}{2}\right)$, FS leads RE or alternatively RE has some predictive information about FS. Given the phase difference we can determine the instantaneous time lag between the time series $x(t)$ as $\Delta T(s,\tau) = \frac{\varnothing_{xy}(\tau,s)}{2\pi f(\tau)}$. here $f(\tau)$ is the frequency that links to the scale τ. For multiple wavelet see appendix A.

3.4. *Construction of financial market stress index*

FSI is carried out by creating the total stress index, which provides information about the financial market condition. We used quartely data spanning from January 1998 to December 2021 which cover major economic events in recent time. Drawing on the methodology approach by Ref. [52,117–121], we capture different types of risk from different dimensions of financial market by employing five market level indicators for each of the BRICS economies. These are banking sector, money market, equity market foreign exchange market pressure and bond market. We employ these indicators because they exhibit the highest level of uncertainty and distress during systemic risk [119]. These five components collectively contribute to linking the level of financial stress with significant fluctuations in asset prices, sudden shifts in uncertainty, risk appetite, liquidity conditions, credit availability, and/or financial intermediation[120,121]. The choice of sub-indices was limited by data consideration. The banking stress is composed of three variables: banking beta,[2] banking equity[3] volatility and negative banking.[4] The money market stress index is made up of two variables: inverted spread and bank credit. Following Mundra & Bicchal [122] and MacDonald et al. [119]. We computed the inverted spread as the difference between 5 years and 91 days of TB and the bank credit as the difference between the bank offer rate and TB. The equity market comprises two variables: negative equity[8] and volatility of the equity market volatility[7]. We measure debt as a yield differential between 10-year government bond and 2 years government bond [120]. Foreign exchange market pressure is computed using Eichengreen et al. [123] [5] which has been used by well documented studies[120,121]. We employ economic policy uncertainty index (EPU), geopolitical uncertainty (GEPO), global energy uncertainty index(GEUI) as market uncertainties following the strands of literature [52,124,125]. Data for EPU, GEPO and GEUI were gleaned from Baumeister et al. [126], and Data for renewable energy were gleaned from OECD data base.[6] We use principal components analysis (PCA) to aggregates all the five sub-indices. PCA is a statistical technique that transforms a set of correlated variables into a new set of uncorrelated linear combinations. This transformation is based on the covariance matrix of the input indicators, with decomposition determined by their corresponding eigenvalues. In this context, the first principal component is extracted, and its associated factor loadings serve as weights for aggregating the individual financial stress indicators into a composite measure. This method enhances the robustness of the index by capturing the maximum variance in the underlying data structure. The dataset for this study is collected at a quartely frequency however, since data for RE are only available on an annual basis, we employ cubic spline interpolation to convert the annual data into quartely series. This approach ensures a smooth transition between data points while preserving the underlying trend and structure of the original series. Our methodology follows the interpolation technique[7] outlined in Chiranjivi & Sensarma [127], which has been validated for high-frequency disaggregation in similar financial and macroeconomic studies. All data used for the construction of FSI were gleaned from data streams.

3.5. *Preliminary analysis*

3.5.1. *Descriptive statistics*

Table 1 report statistical moments along with the normality test, unit root test. The standard deviation value exhibits that renewable energy has the least volatility whereas financial stress indices depict the most volatile behaviour. We also notice that the skewness values for financial

---

[2] The banking beta is defined as: $\beta_{i\ t} = \frac{COV(r,m)}{var(m)}$ where r, m represents banking sector and overall market stock price returns[121]. If the $\beta > 1$ it suggests that banking sector moves more than proportionately than the overall equity market. This implies that the banking sector is relatively risky and would associated the higher likelihood of banking crisis [121]. Twelve months rolling covariance and variance were used to compute the beta value of banking sector.To capture the banking related FS, the banking beta was recorded only when the banking returns were lower than overall market returns.

[3] This was calculated using GARCH (1,1).

[4] Computed as the monthly change in the equity index multiply -1 so that a decline in equity corresponds to increase in equity market stress [121].

[5] It is defined as $\frac{empi_{it}(\Delta ex_{it} - \mu_{i\Delta ex})}{\sigma_{i\Delta ex}} - \frac{empi_{it}(\Delta resv_{it} - \mu_{i\Delta resv})}{\sigma_{i\Delta resv}}$ where Δex and $\Delta resv$ depicts quarterly on quarterly percentage change in foreign exchange rate of local currency per US dollar and foreign exchange reserve. σ and μ are standard deviation and mean respectively.

[6] https://data.oecd.org/energy/renewable-energy.htm.

[7] Cubic splines may smooth out small but important fluctuations in data, leading to a loss of crucial information.

Table 1
Descriptive statistics.

Financial stress	Mean	Variance	Skewness	Ex.Kurtosis	JB	ERS	Q(20)	Q^2(20)
South Africa	−0.007	1.068	1.19	0.618	24.170***	−1.493	40.64	10.11
Brazil	−0.008	1.067	−0.562	1.495	13.985***	−3.541	43.141	15.097
China	−0.429	1.572	−0.253	0.098	1.059	−2.519	91.945	32.943
India	0.004	1.092	0.128	−0.635	1.874	−1.326	33.916	14.594
Russia	−0.008	1.624	1.303	2.377	49.777***	−0.895	31.847	10.551
Renewable energy								
South Africa	0.841	0.014	0.673	−0.881	10.351***	−2.733	243.102	225.229
Brazil	0.211	0	−0.037	−0.609	1.504	−5	248.99	248.641
China	0.063	0.005	−0.467	−1.368	10.977***	−2.306	244.552	302.368
India	0.147	0.001	−3.278	13.984	954.123***	−1.526	14.362	104.789
Russia	0.435	0.001	0.147	−1.217	6.268**	−3.1	160.514	159.31
Uncertainties								
EPU	0.861	0.026	−1.155	1.694	12.291***	−2.492	63.664	62.767
GEUI	0.12	0.002	−1.587	6.034	185.938***	−1.836	16.605	23.298
GEPO	0.294	0.001	1.011	2.26	36.777***	−2.68	44.326	40.016

Notes (***), (**) and (*) denote significance at 1 %,5 %, and 10 % significance level, respectively; Kurtosis test; Anscombe & Glynn [128] JB; Jarque & Bera [129] normality test; ERS; Elliott; Rothenberg et al. [130] Unit root test; $Q(20)$ and $Q^2(20)$ shows the Ljung-Box p-value for residuals and sequare residualin with the lags 10 and 20 respectively [131]. GEUI represents the global energy uncertanity index and GEPO denotes geopolitical uncertainty index.

stress indices in BRICS are positively skewed except for China and Brazil which exhibit negatively skewed. We observed that renewable energy for Russia and South Africa is positively skewed whereas the rest are negatively skewed. This implies that there is a high tendency to obtain a negative extreme value given our sample size, which covers major economic events. Apart from geopolitical uncertainty, and renewable energy for India, the kurtosis values of the series are below the conventional standard of 3, which implies that the series have a flatter than normal distribution with shorter tail. Intuitively, kurtosis statistics show the relative difference between normal distributions and probability distributions. From the summary statistics, we notice that ERS statistics indicates that all the series are I(0) except Russia and South Africa for monetary policy and financial stress indices are I(1). The presence of serial correlation based on 20 lags confirmed by Ljung-Box statistics (Q, Q2) evidences the possibility of serial correlation in residuals (Q (20)) and square residual (Q^2(20)) for all-time series.

3.6. Broock-Dechert-Scheinkman (BDS) nonlinearity test

Table 2 display the z statistics estimated using Broock et al. [132] nonlinearity test to evaluate the appropriateness of BQQR and MQQR analysis applied in this study. If the null hypothesis is rejected, it suggests that the observed variables exhibit nonlinearity. As presented in Table 2, we rejected the null hypothesis of independence and identically distributed at a 1 % significance level. Our results reveal that nonlinearity is present in all variables which underscores the suitability of the BQQR and MQQR method for this study. Fig. 1 depicts the financial market stress for the BRICS economies. The positive value of the index denotes the stress period, while the negative value depicts the low stress period. We observed that the spike of the market stress slightly differs from one economic bloc to the other. This variation in the spikes among BRICS markets is associated with their strength of financial and trade links with global economy.

Table 2
Nonlinearity of BDS

Variables	Embedded dimension				
Renewable energy	2	3	4	5	6
Brazil	32.562[a]	33.628[a]	34.702[a]	36.542[a]	39.242[a]
Russia	36.317[a]	37.798[a]	39.151[a]	40.765[a]	43.445[a]
India	21.621[a]	22.007[a]	22.855[a]	24.630[a]	28.487[a]
China	36.423[a]	38.373[a]	41.050[a]	45.193[a]	51.050[a]
South Africa	28.225[a]	29.387[a]	31.391[a]	35.329[a]	40.663[a]
Financial stress					
Brazil	12.671[a]	12.519[a]	12.743[a]	13.060[a]	13.453[a]
Russia	13.751[a]	13.869[a]	14.297[a]	14.929[a]	15.829[a]
India	20.704[a]	21.387[a]	21.206[a]	21.280[a]	21.955[a]
China	17.520[a]	17.867[a]	18.514[a]	19.064[a]	19.567[a]
South Africa	10.269[a]	11.865[a]	13.669[a]	15.035[a]	16.421[a]
Policy uncertainties					
Economic policy uncertainty	29.590[a]	30.938[a]	32.316[a]	34.418[a]	37.528[a]
Energy uncertainty index	11.515[a]	11.506[a]	11.801[a]	11.748[a]	12.109[a]
Geopolitical index	11.465[a]	12.306[a]	12.824[a]	13.753[a]	14.964[a]

Note: Notes (a), (b) and (c) indicate the rejection of null hypothesis that the series are independent and identically distributed at 1 % 5 % and 10 % significance level.

4. Empirical results and discussion

4.1. Bivariate and multivariate quantile-on-quantile regression

Given that the MQQR approach offers more comprehensive information on the relationship between the nexus, our empirical analysis focuses on this approach to expand our understanding of the intriguing interplay between the nexus in BRICS economies. we categorize the quantile range 0.05–0.35 as lower quantile (bullish or good market), 0.45 to 0.65 as median quantile (average market) and 0.70–0.95 as upper quantile (bad market or bearish). To obtain sense of these quantiles, we present the results in three dimensional plots (see Figs. 2 and 3). This is performed by selecting θ and the effect of the τ-quantile. The effect of RE is captured by the slope coefficient $\beta_1(\theta,\tau)$. The estimates of $\beta_1(\theta,\tau)$ on z-axis against the quantiles of θ on the x-axis and quantiles of τ in the *y-axis.* We plotted the slope coefficients estimated using bivariate and multivariate QQR (see Figs. 2 and 3). The graphs display (see Figs. 2 and 3) indicate how the τ-quantile of financial stress influences renewable energy investment. The θth depicts high and low quantiles representing rising and falling of renewable energy investments respectively. To verify the reliability of the MQQR estimate in Fig. 3, we plotted the slope of the coefficient estimate using the bivariate approach of QR see ([133,134]; [135]; [136]).

We present the plot of the multivariate QR and MQQR slopes esti-

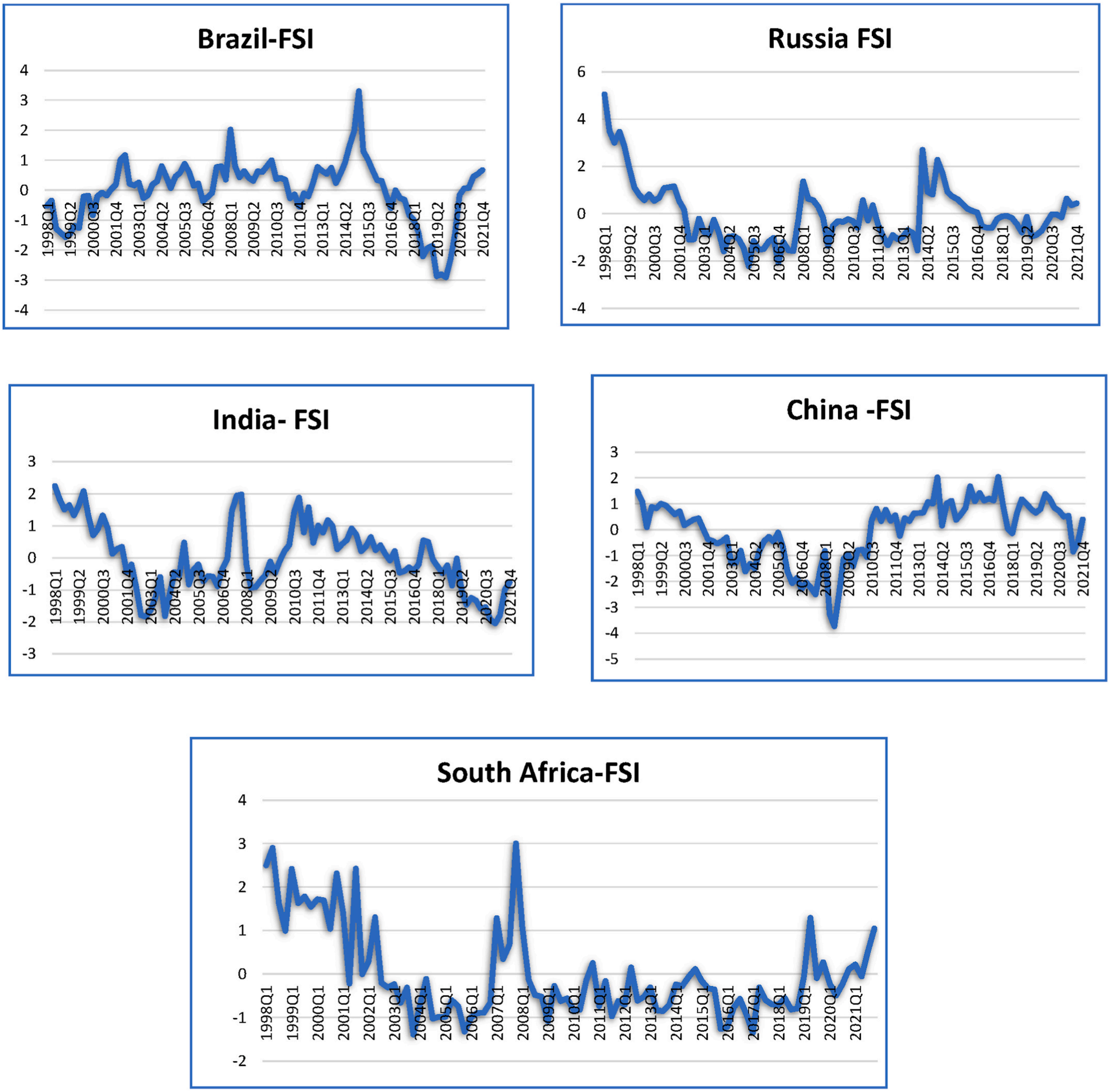


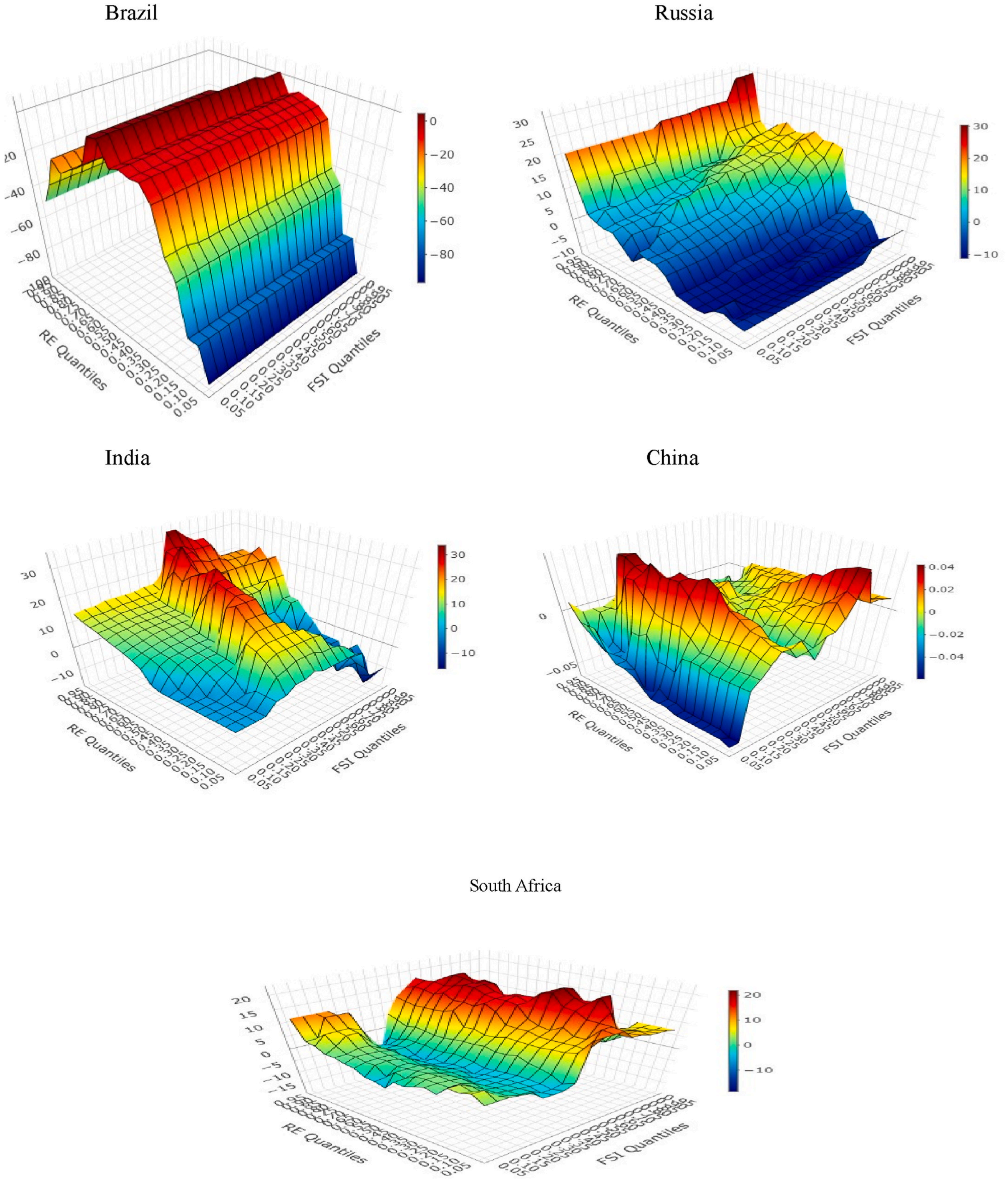
Fig. 1. Financial stress index for BRICS economies.

mated for each quantiles of the nexus.[8] We present a graphical presentation using line graph (see Fig. 10 of Annex A), for both the MQR and MQQR slope coefficients estimated for the quantile for FS and RE. To confirm the robustness of coefficient of MQQR and QQR, we consider the bivariate case of the QR model. As shown in the line graph (see Fig. 10 of Annex A) there is clearly a similarity between the average MQQR and the estimates of the MQR, but in the case of the BQR, there is a slight difference in terms of magnitude and, in some cases, the sign the of coefficients. The results of the MQR and MQQR methods confirmed the results of the multivariate QQR by the closeness in the pattern of both MQQR and MQR across the entire distribution of quantiles reported in the study.

In Fig. 1 we observe that RE and FS have mix of positive and negative relationships for China Russia South Africa and India. The strength of these condition varies across market states (bearish normal, and bullish) for each economic bloc. For instance, in the bivariate QQR (see Fig. 2), for South Africa when RE and FSI are in the lower quantile ($\tau = 0.05 \sim 0.25$) a positive association is observed and a negative

---

[8] The multivariate QR(MQR) estimate is based on θ quantile of RE and FS. The RE and FS parameters are indexed by θ and τ respectively which only assess the effect of independent variables on the dependent variables. The MQQR approach regresses the θ quantile on the τ quantile of the RE and as result, its parameter is indexed by θ and τ. This is expressed as $\widehat{y}'_o(\theta) \equiv \widehat{\beta}_o(\theta) = \frac{1}{k}\sum_p \widehat{\beta}_o(\theta, \tau)\widehat{y}'_1(\theta) \equiv \widehat{\beta}_o(\theta) = \frac{1}{k}\sum_p \widehat{\beta}_1(\theta, \tau)$. To validate the estimate of MQQR, we compare the τ averaged $\widehat{y}'_o(\theta)$ and $\widehat{y}'_1(\theta)$ with the parameters derived from QR estimation ($\widehat{y}_o(\theta)$ and $\widehat{y}_1(\theta)$).



Brazil

Russia

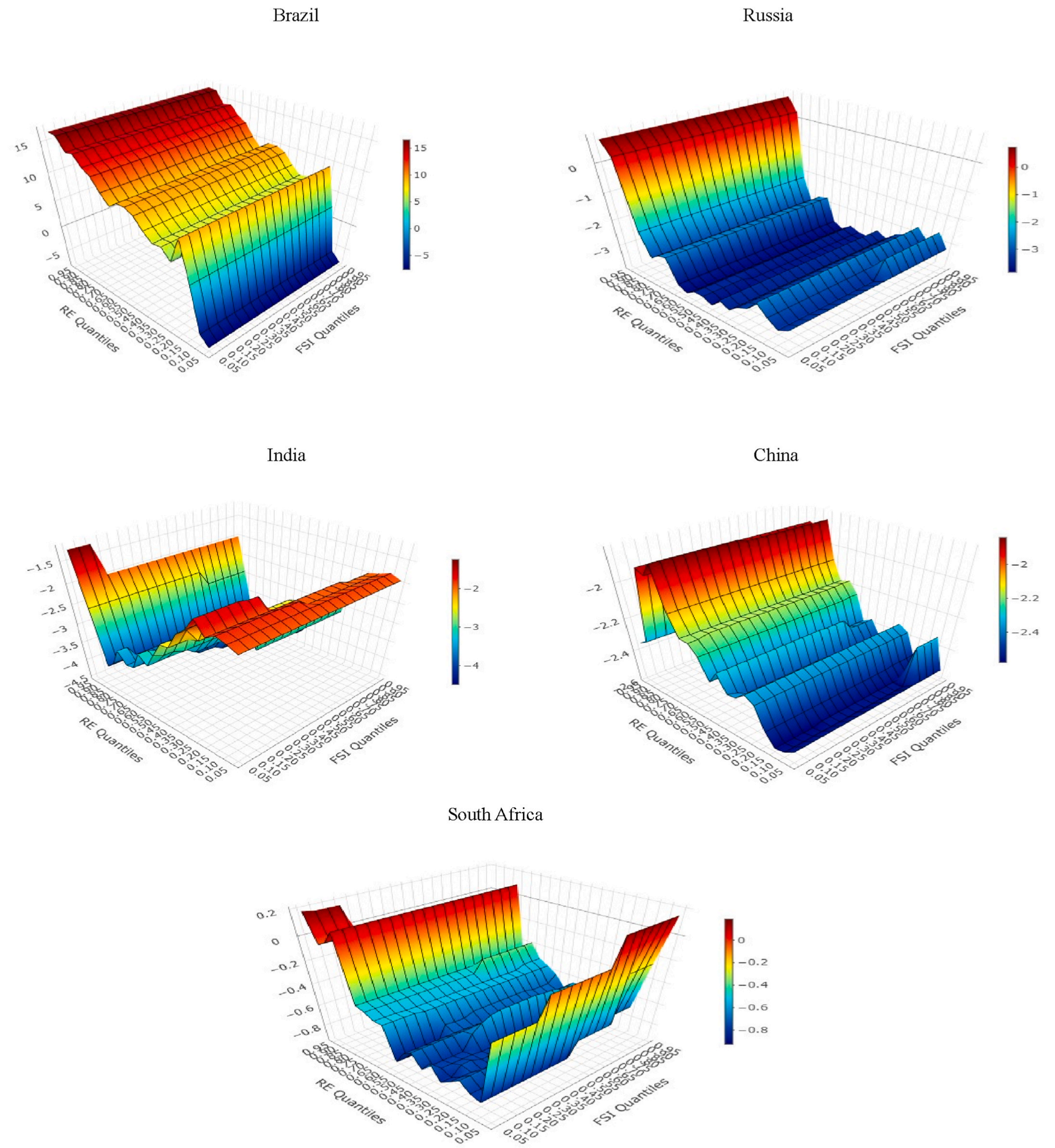
India

China

South Africa

Fig. 2. Bivariate QQR between FS and RE in BRICS economies.

association is also observed in the upper quantile($\tau = 0.85 \sim 0.95$). Conversely, when RE falls in the lower quantile in Russia, a negative association is observed whereas a positive relationship is observed in the upper quantiles. This implies that market stress has a disruptive effect on RE at the lower quantile, which may slow down RE development. In Brazil, the bivariate QQR shows that there is a relationship between RE and FSI which is negatively related across the entire quantile distribution, whereas there is a positive association between RE and FSI for India


Brazil

Russia

India

China

South Africa

Fig. 3. Multivariate QQR between FS and RE in BRICS economies.

across the quantile distribution with high magnitude impact. However, in the case of India the greatest impact of market stress on RE appear in the middle quantile which implies that high market stress in India causes a greater decrease in RE (see Fig. 2). The negative impact of market stress on RE across all quantiles in Brazil suggests that high financial market stress causes a greater decline in RE investment in Brazil. In China the results show that FS reduces RE in the medium and long-term, revealing that high market stress translates into a higher decline in RE. We also notice that as FS declines in the lower quantile suggest that market stress has less of an impact on RE. From the above analysis, we can see that the QQR is a single -variate- based technique which ignores other factors that can influence RE investment. Following the MQQR approach, by Alola et al. [109] we include other market uncertainties (geopolitical risk, economic policy uncertainties and energy policy

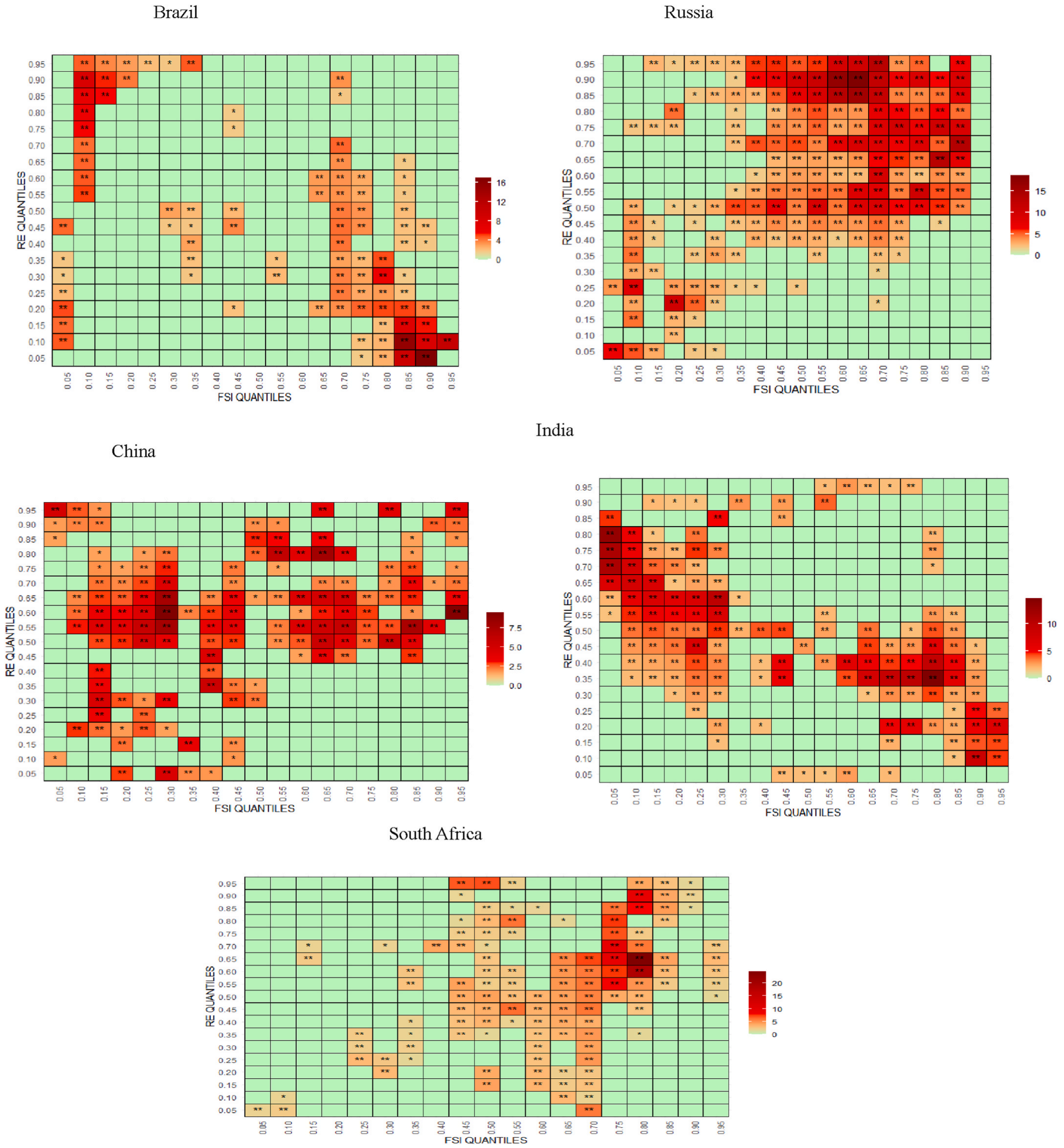


Fig. 4. Quantile-on-Quantile granger causality between RE and FSI in BRICS economies.
Note: The heatmap shows the test statistics for RE and FSI. Here ** and * depicts 5 % and 10 % significance level. For the interpretation of the colours in the heatmap the reader should refer to the web version of the article.

uncertainties), thus allowing us to assess the relationship. between the quantiles of the dependent variable and the quantiles of independent variables. The plots in Fig. 3 show the impact of τ^{th} on renewable energy investment on the θ^{th} quantile of the combined effect of FS. In contrast to the bivariate QQR we observed a mix of positive and negative relationships in the lower and middle quantiles for Brazil and China. Similar observation also found for South, India and Russia for MQQR in contrast to bivariate QQR.

This heterogeneous impact of both positive and negative across the quantile distribution underscores the complex and time-varying relationship between RE and FSI, with the outcome depending on the market conditions. The negative and positive relationship between the

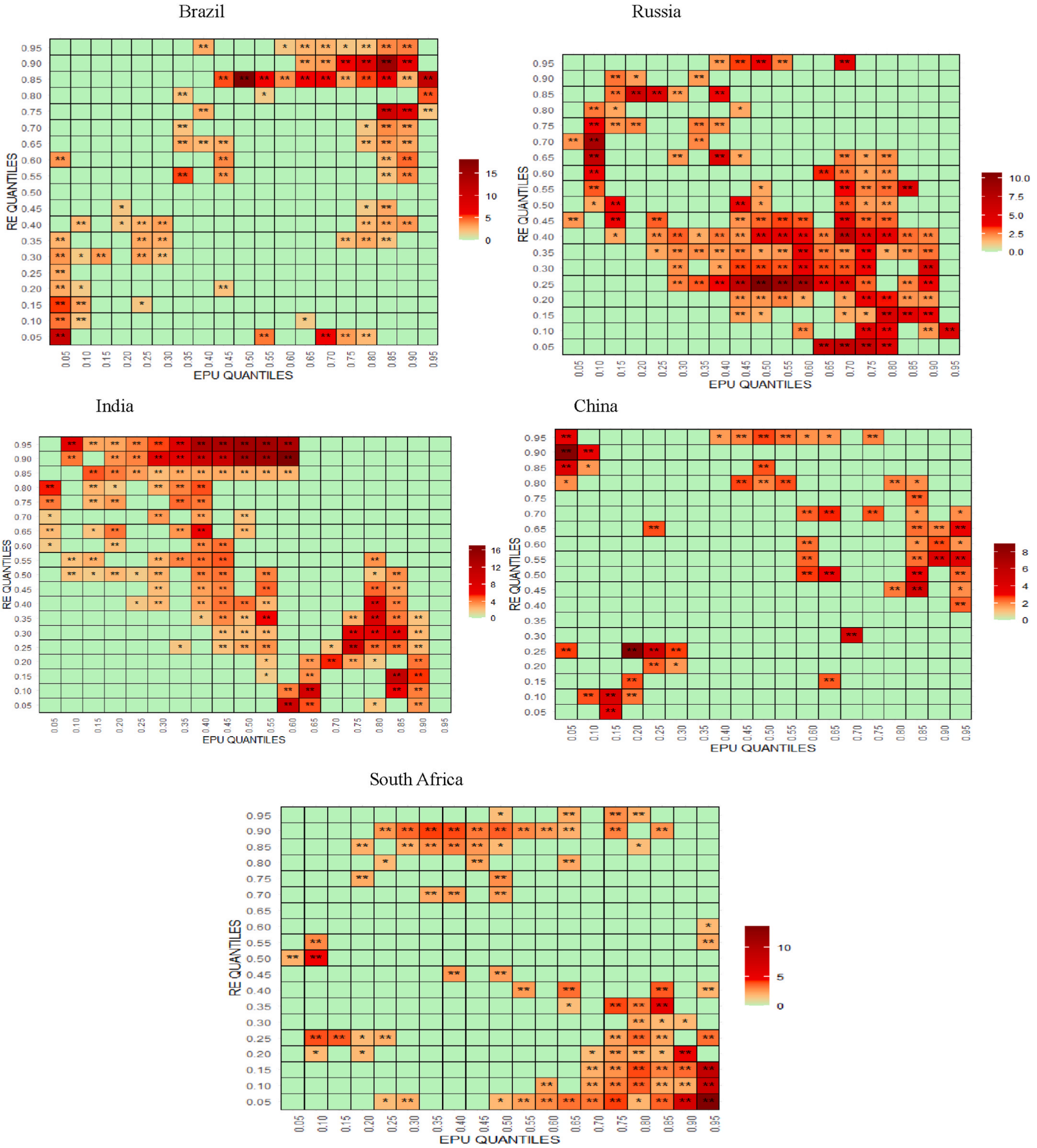


Fig. 5. Quantile-on-Quantile granger causality between RE and EPU for BRICS.
Note: The heatmap shows the test statistics for RE and FSI. Here ** and * represent 5 % and 10 % significance level. For the interpretation of the colours in the heatmap the reader should refer to the web version of the article.

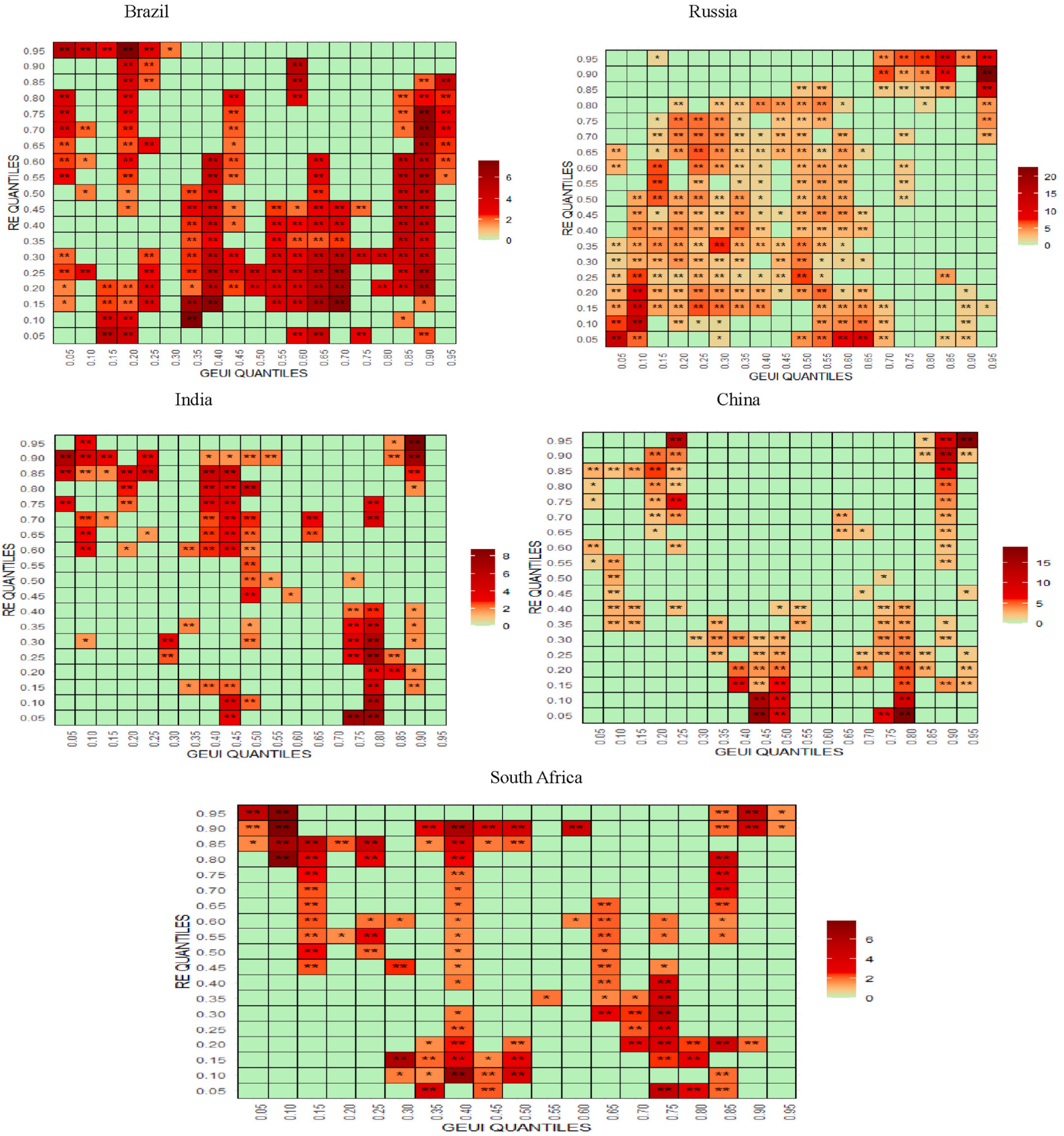


Fig. 6. Quantile-on-Quantile granger causality between RE and GEUI in BRICS econmies.
Note: The heatmap shows the test statistics for RE and FSI. Here ** and * depicts 5 % and 10 % significance level. For the interpretation of the colours in the heatmap the reader should refer to the web version of the article.

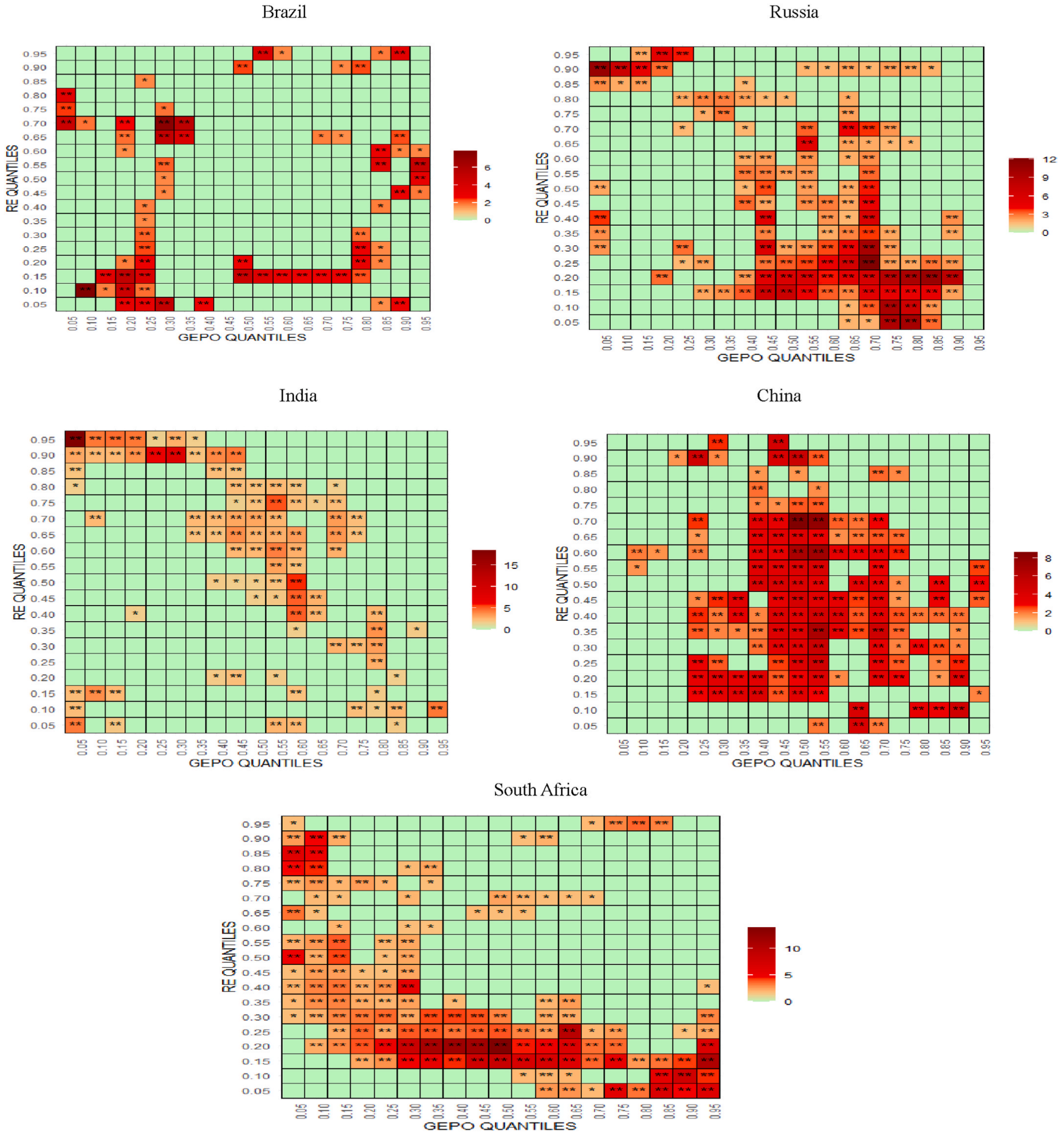


Fig. 7. Quantile-on-Quantile granger causality between RE and GEPO for BRICS economies.
Note: The heatmap shows the test statistics for RE and FSI. Here ** and * represent 5 % and 10 % significance level. For the interpretation of the colours in the heatmap the reader should refer to the web version of the article.

nexus reflects the instability of financial conditions stemming from market uncertainties, which mostly occurs at extreme quantiles. The MQQR finding clearly reveals how misleading the bivariate QQR is if other variables are not considered. This findings was consistent with the work of Balcilar et al. [137] Balcilar et al. [138] and Alola et al. [109]. From the MQQR analysis it is evident that after considering other market

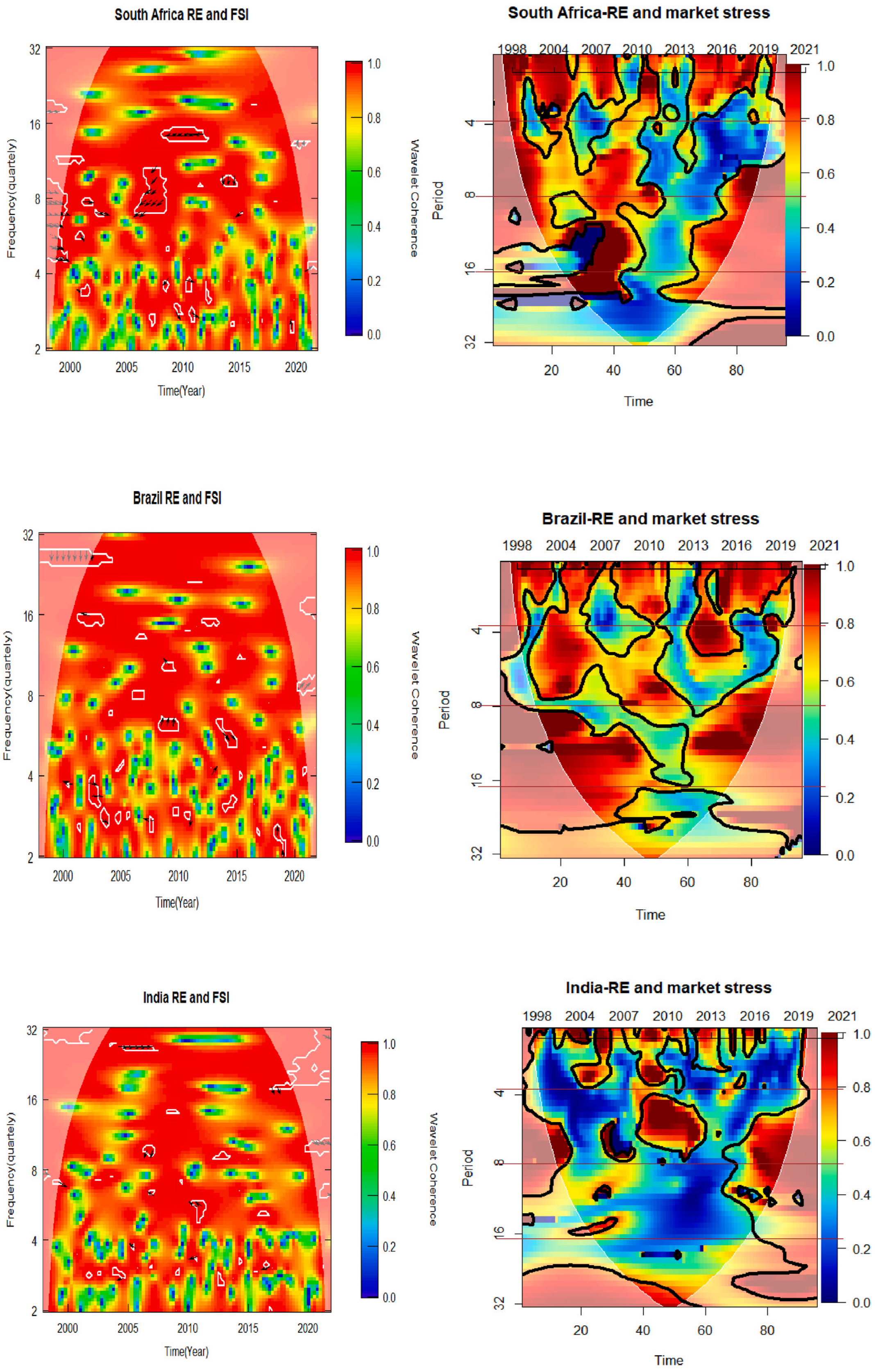
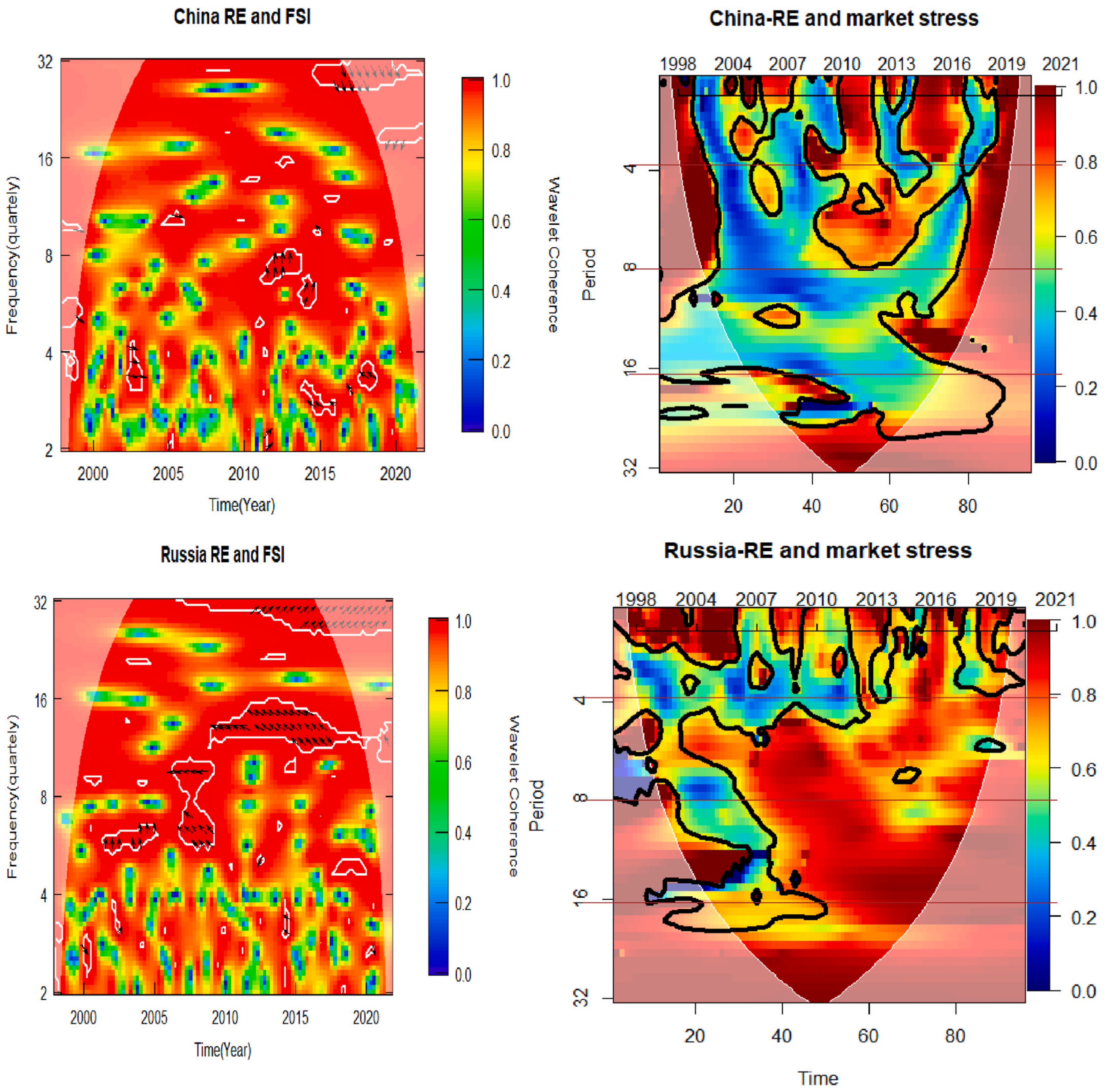


Fig. 8. Bivariate and multivariate wavelet coherence of FSI and BRICS economies.


China RE and FSI

China-RE and market stress

Russia RE and FSI

Russia-RE and market stress

Fig. 8. (*continued*).

uncertainties (geopolitics, economic policy uncertainty and energy uncertainty), market stress hinders RE investment at the extreme quantile. This implies that an increase in market uncertainty poses a significant downside risk to climate investment.

4.2. Quantile-on-qunatile granger causality

Following Adebayo & Özkan [139], we employed quantile-on-quantile granger causality(QQGC) to validate our results of both bivariate and multivariate QQR. Figs. 4–7 depicts the result of QQGC. The results in Fig. 4 reveal that the FSI granger causes RE across the quantile distribution for Russia, India, and China. However, we notice that in the lower and medium quantile for Brazil, FSI does not cause RE. This suggests that there is a unidirectional relationship between RE and FSI. The findings are similar to those who highlight that FS and RE are unidirectional in the normal market[27,99] and granger cause at the extreme quantile. The prominence of FS on RE across all quantile distributions divulges that renewable energy remains reliant on market stability.

Turning to exogenous variables (EPU, GEUI, GEPO), see Figs. 5–7, we observe that when the quantiles of both EPU and RE (see Fig. 5) are considered for Brazil, Russia, India, and South Africa, EPU granger cause RE investment. The results also reveal that the magnitude of the impact of granger cause increase from the lower to upper quantile. This finding aligns of Khan & Su [42] who argued the EPU affects RE in the upper quantile more than in the lower quantile. The findings also indicate that the EPU acts as a major catalyst to stimulate and drive a changes in RE investments. This finding is similar to that in Fig. 6 which reveals that global energy uncertainty holds a substantial prediction of RE investment across the entire quantile distribution for Brazil, India, South Africa and Russia. This finding demonstrates that a high GEUI has a significant influence on RE investments. Initiatives to reduce GEUI will have the opportunity to spur RE investment. By constrast, uncertain measures may force businesses to overexploit resources in pursuit of temporary advantages, potentially comprising environmental sustainability. Conversely, initiatives designed to mitigate the uncertainty can encourage investment in green innovation, ultimately benefiting the environment [139]. A similar finding (see Fig. 7) was observed across the quantile distribution, except for the lower quantile 0.05 for China and the middle quantile 0.45 for Brazil. As the quantile moves from the lower to the upper range, we observe that GEPO has a substantial influence on RE, indicating that GEPO risks play a crucial role in the emergence of renewable energy, primarily because of energy security, competition for rare metals, and trade disputes that stimulate the transition to renewable energy. This conclusion is particularly relevant to news of adverse events, which tends to significantly increase investor fear, as highlighted by Q. Wang et al. [140] and Xiao et al. [141]. This finding aligns with economic literature which emphasises that climate investment is closely linked to the socioeconomic and political environment[85].

In this regard, rising political tensions, social instability, and economic turmoil may discourage investors from allocating new resources to the construction of new renewable energy facilities. Additionally, X. Wang et al. [142] argue that the increase in geopolitical tensions raises concerns among investors, market participants, and policy makers, which hinder investment in renewable energy and slow economic activity.

According to our analysis the influence of market stress on RE is not solely determined by macroeconomic factors but also by geopolitical and other economic uncertainties. Our findings have a strong policy implications, as they underscore the need and importance of RE investment in BRICS economics. The study recommends that investors and market participants pay attention to these uncertainties rather than rely on fundamental economic elements when making investment decisions. The empirical results, shows that FS exhibits varying effects on RE across different quantiles. This observation supports the heterogeneous market hypothesis proposed by Müller et al. [143], which serve as a guide for investors and policymakers in assessing how systemic risk affects RE. The discovery that in the extreme quantile of FS, has a detrimental impact to RE investment has brought a significant insinuation for investors and market participants that FS indeed poses a significant risk on RE investment as highlighted recently by Miah et al. [10]. It is crucial to acknowledge that both bivariate QQR and MQQR approaches present a static view of the impact on RE, neglecting the temporal dimension of the nexus. In the following section, we utilize time-frequency analyses with wavelet coherence to explore the dynamic nature of this relationship.

4.3. Bivariate and multivariate wavelet analysis

This section discusses the results of the wavelet coherence analysis of bivariate and multivariate wavelet analysis. The scalogram in Fig. 8 on the left-hand side shows a bivariate wavelet analysis. Following the literature, the level of wavelet coherence is displayed using colours on the vertical axis. The heatmap allows for display of the pairwise relationship between pair series coupled with their lag/lead pattern. The arrows in the heatmap display the relationship between the RE and FS. In this regard the arrows (←) and (→) suggest an out-phase and in-phase relationship respectively. The out-phase and in-phase depict the negative(positive) relationship between FS and FS. The arrows (↗) and (↙) shows that RE is leading and arrows (↘) and (↖) suggest FS is leading. The phase difference that fall within the cone of influence(COI) reveals the significant co-movement between RE and FS. The hotter colour(red and yellow) indicates high coherence, and the warmer colour(blue and green) indicates low coherence. Following Mensi et al. [144], we define the frequency a short term(2–4 months) medium term(8–16 months) and long term(32–64 months). The right-hand side of Fig. 8 display multiple wavelets. The power colour code ranges from blue (low power) to red (high power). A higher intensity (red colour) represents a stronger correlation between FS and market stress at a specific scale or frequency whereas a lower intensity (blue colour) indicates a weaker correlation. The thick black contour depicts the 5 % significance level against red noise which is calculated from Monte Carlo simulations using phase randomized surrogate series[145]. The cone of the influence represents the area affected by the edge effect, and shows a lighter black line.

Taking into consideration the above guide, and reference to the pictorial presentation in Fig. 8, we observe several arrows is the middle frequency band that feature a high degree of coherence in the case of South Africa. The arrows in this frequency band show a downward trajectory, confirming the existence of a lead/lag relationship between RE and FS between the period of 2005–2010. The phase difference in this region suggests that FS drives RE. This implies that FS has a significant influence on RE investment.The phase difference ranging from $\left(\pi, \frac{\pi}{2}\right)$ in the low frequency from 2000 to 2004 and 2010–2012, indicating that pair series are in-phase. During this period, we noticed that market stress was high (see Fig. 1), which demonstrates the comovement between the pair series. However at the upper frequency around 2009–2014 we observed a weak correlation between RE and FS. After considering the exogenous factors (right-hand side of Fig. 8) we observe RE highly sensitive to market stress across the frequency space. Thus inferred that the combined effect of market stress on RE is significantly stronger across the time frequency space than the bivariate wavelet. We find that the combined effect of market stress exerts a significant influence on RE in South Africa. Noticeably we observed a greater coherence in Brazil, China, and Russia across the frequency space for the combine effect of market stress on RE as compared to bivariate coherence. Observably, the phase difference in the lower and medium frequency band from 2002 to 2020 for bivariate coherence(see left-hand side of Fig. 8) ranges from 0 to $\frac{\pi}{2}$ implying that FS drives RE for Brazil, Russia, India, and China. However the directional arrow oriented to (←) suggest a weak correlation between RE and FS. This can be found in the case of Russia, Brazil, India at the lower and medium frequencies from 2004 to 2009. Noticebly we observe a relatively warmer island at the upper frequency band with the positioning arrows (↗) in the case Russia suggesting that FS plays a driving role on RE investment. This finding is consistent with similar observation by Gaies & Chaâbane [27], who find that financial stress significantly drives green investment. Given the relatively high coherence for the combined impact for Russia, India, China and Brazil (see Fig. 8 right hand) we document RE is more sensitive to FS when we combined effect of GEPO, EPU and GEU across the time scale of 4–32 for Brazil, South Africa and Russia around 1998, 2004, 2007, 2010, 2014, 2016 2020 and 2021 and time of scale of 4–8 for China and India around 2004, 2009 2013, 2014 2017 and 2020. The significant correlation during this period reflect major economic event. This finding aligns with the work of Husain et al. [146]; Khan & Su [42] and Jian & Zhengjie [147].

4.4. Discussion

In investigating the relationship between financial market stress and renewable energy, our findings draw important innovative conclusions from our analytical framework. Through the application of bivariate QQR and multivariate QQR, the findings explicate that the effect of market stress on RE is predominantly negative under extreme quantiles. This implies that FS has strongest negative impacts on RE during economic downturns. That is when financial markets are in crisis, funding of RE project becomes much harder to secure due to systemic risk and this significantly reduce investor confidence. These findings are also consistent with previous studies demonstrating that financial stress has a negative impact on total investment through the real-economy channel [148–150] and investment channel [25,151]. We document that RE although considered as a sustainable choice they are exposed to financial market stress during bearish and bullish market conditions. Contrarily, in the extreme quantile, we observed that both BQQR and MQQR reveals that during normal market there is a positive relationship between RE and FS in India, Russia, and South Africa. This suggests that investment in RE for this market bloc is safer as we observe a relatively low market stress. This finding aligns with a similar study of Gaies & Chaâbane [27], who find a positive effect of financial stress and green stock. The mixed effect of RE and FS across various market conditions explicates that FS can have varying effects on RE. This could have implications for risk management strategies, as investors and policymakers may need to consider the specific market conditions when assessing the potential on RE. These complexities are highlighted by the asymmetrical responsiveness of various market conditions induced by shocks, suggesting that linear models may be insufficient to capture the dynamics of the nexus. To accurately model this intricate dynamics, more sophisticated models that account for these asymmetries may be necessary. The finding that RE exhibit negative relationships, particularly at the lower tails of GEPO and GEU in China, Russia and South Africa has implications for risk management. During periods of high geopolitical risk, these markets may be particularly vulnerable to negative shocks, and investors and policymakers may need to take proactive measures to mitigate this risk. Furthermore, the continuous variations in EPU across quantile for India, Brazil and Russia highlight the need for ongoing monitoring and assessment market stress in these economics to understand the potential impacts of these perturbations and develop appropriate response strategies.

The results of the bivariate and multivariate wavelet coherence analysis highlight a strong correlation between RE and FS, from short-term to long term. Interestingly, this connection appear to be linked to periods of uncertainties triggered by financial turmoil such as the GFC, the EDC, the oil price plung, trade war, the emergence of Brexit, and the COVID-19 pandemic. These findings substantiate the work of Horky et al. [152], Das et al. [153], Horky et al. [152] and Alqaralleh et al. [154] who documents that the relationship between green market and FS differ in time scale across investment horizon with the varying effect of market uncertainty. Therefore, we infer that the effect of FS on RE is vulnerable to macroeconomic event and global sentiment. The significant shock caused by these events has a persistent impact on RE. Observably, we note that the continuing influence of market stress on RE may be due to the perceived risk associated with RE, which could be more sensitive to overall market stress. Evidence from multivariate wavelet coherence shows that RE is affected not only by specific factors but also market uncertainties such as GEOP, EPU and energy GEUI.

5. Robutness analysis

To ensure the reliability and accuracy of our index, we use equal-variance weighting technique. In this approach, each components is measured as it deviation from the mean and weighted by the inverse of its variance [121]. This weighting scheme normalizes for differences in volatility, enables a systematic decomposition of stress components [121]. Since the five market-level indicators are expressed in different form and magnitudes, standardization is necessary to ensure comparability.[9] The standardized subindices are then aggregated into a single composite FSI using a variance-equal weighting approach, which adjust the difference in volatility across indicators[10]. To gain deeper insights into the tail dependence and co-movement between RE and FS, we extend the analysis from subsection 4.1 by employing the cross-quantilogram (CQ) framework proposed by Han et al. [155,156]. This methodology quantifies dependence across different quantile pairs, offering a comprehensive characterization of the distributional dynamics, including central tendencies, extreme negative tail events, and extreme positive fluctuations [157]. We describe this approach in Appendix B. Turning our attention to the estimates results obtained, we report in Fig. 9A–D. In the heatmap, the x-axis denotes the quantiles of FS while the y-axis indicates the quantiles of RE. The intensity of the estimated CQ correlation spans between deep blue (highly negative significant dependence and deep red (highly positive significant). This is represented by the multicolour bar displayed at the right side of the heatmap. From the heat map in 9A the dominance of the red colour in upper quantile for BRICS econmies reveal that at the higher quantile of FS and associated with higher quantile of RE. This implies that as market stress increases, it significantly affect RE projects in BRICS economies. However the after controlling GEPO and GEUI we observed that (see Fig. 9B & C) the directional predictability between RE and FS at the upper quantiles is exacerbated by GEPO and GEUI. This is not the case after controlling EPU(see Fig. 9D) as we observed a weak correlation between FS and RE. The heatmap reported in Fig. 9A–D, re-confirm our findings obtained in sub-section 4.1-4.3.

6. Conclusion policy and recommendation

Over the years researchers and economist have unanimously argued that financial market stress affects economic activity. Monitoring the dynamics of financial market is critical for macroeconomic surveillance and economic activities. For this reason, we constructed market stress index to investigate the effect of FS on RE in BRICS economics covering from 1998 to 2021 using BQQ and MQQR regression analysis supplemented by wavelet coherence. The empirical result suggests that the

---

[9] The standardization follows these steps. Each indicators is transformed into standardized z -score as $Z_{i,t} = \frac{X_{i,t}-u_i}{\sigma_i}$

Where u_i is the mean and σ_i is the standard deviation of the indicator i. This ensure that all indicators have a mean zero and a standard deviation of one, preventing any single indicator from dominating the FSI due to scle difference.

[10] The weight assigned to each indicator is inversely proportional to it s variance as follows; $w_{i,} = \frac{1}{\sigma_i^2}$. This is ensure that volatile indicator do not disaproportionately influence index. The FSI is then computed as the weighted sum of the standardized subindices as follows: $fsi_t = \sum_{i=1}^{5} w_i Z_{i,t}$.

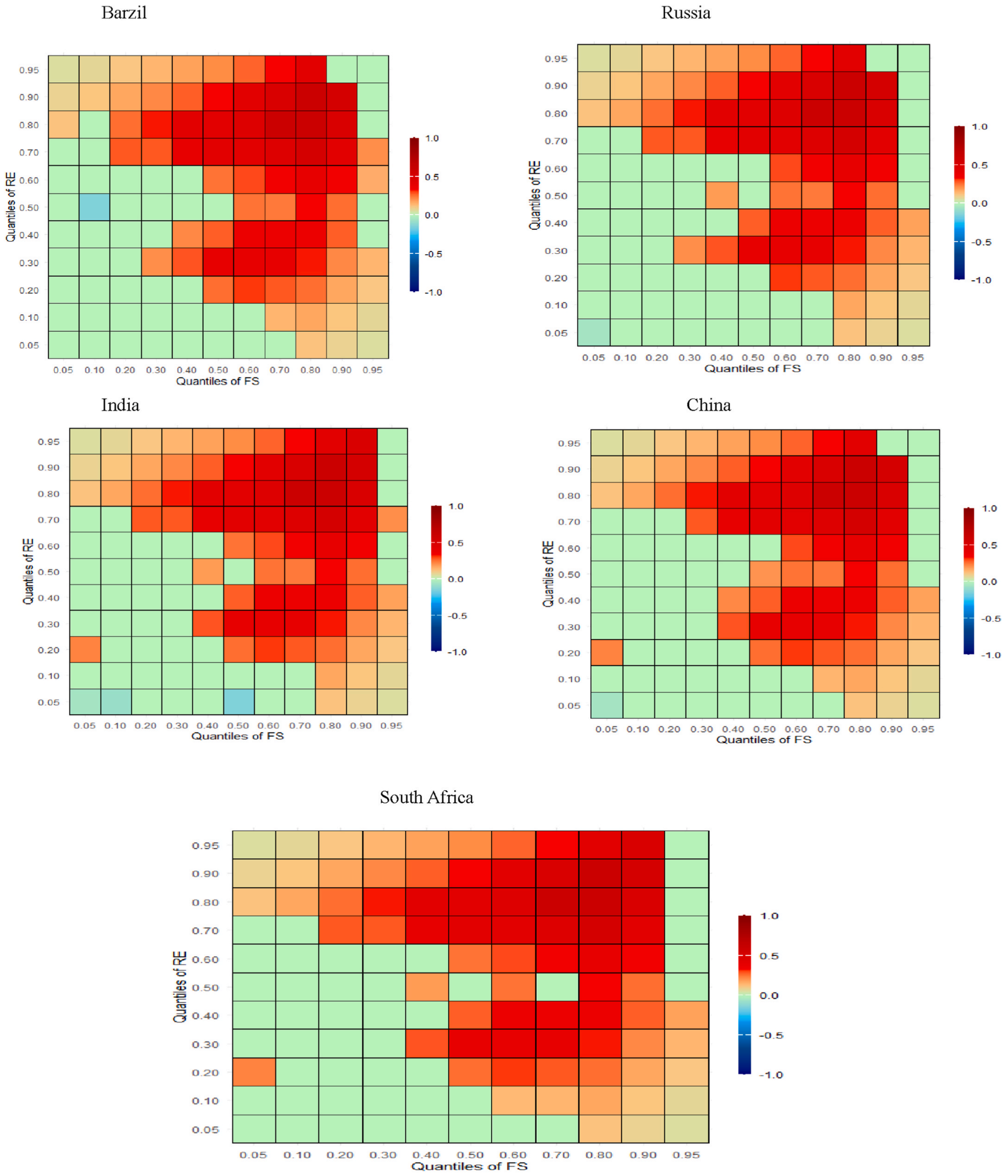


Fig. 9A. Cross -quantilogram plot between RE and FS for BRICS nation. The scale presents the intensity and the direction of variables.

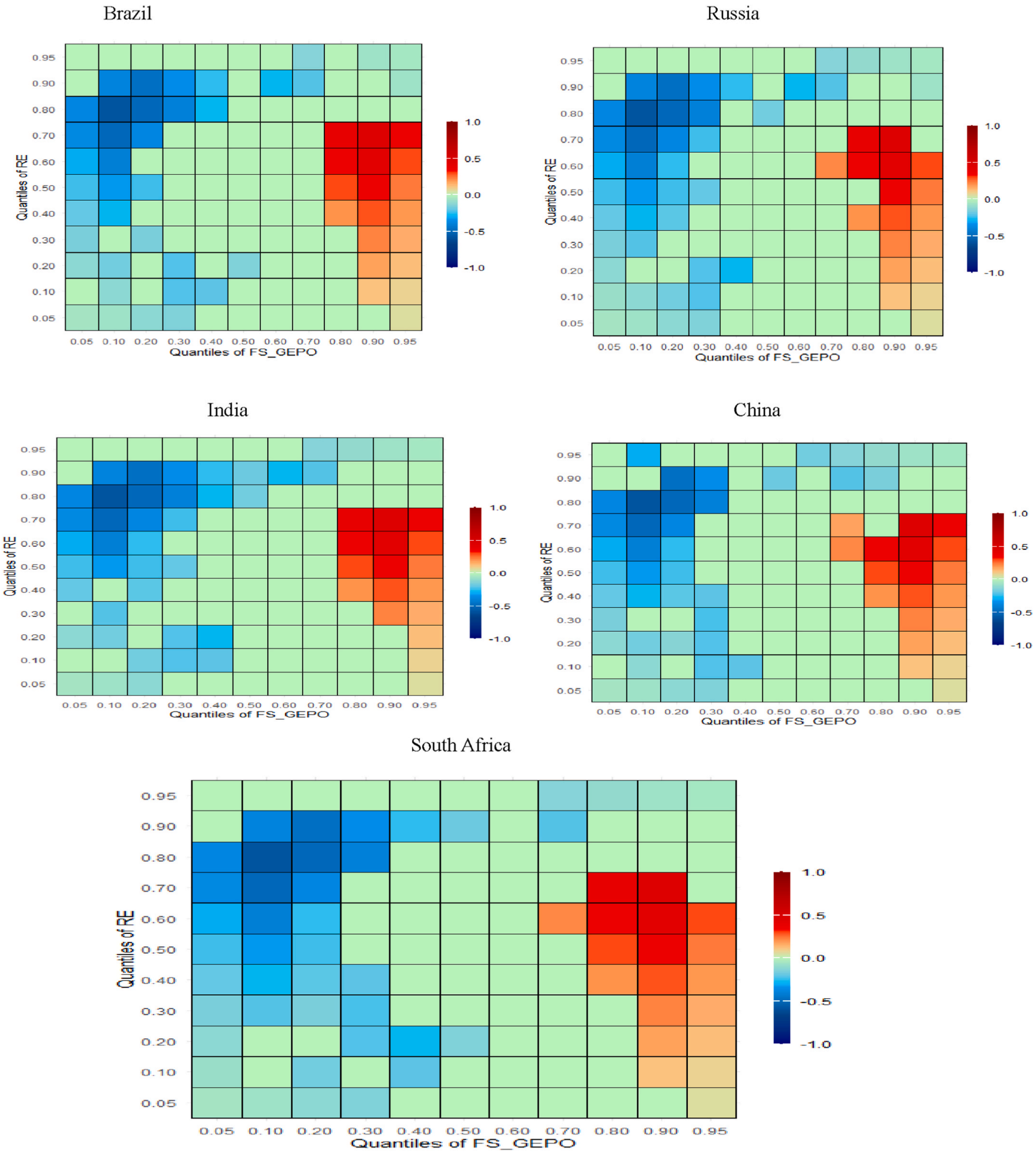
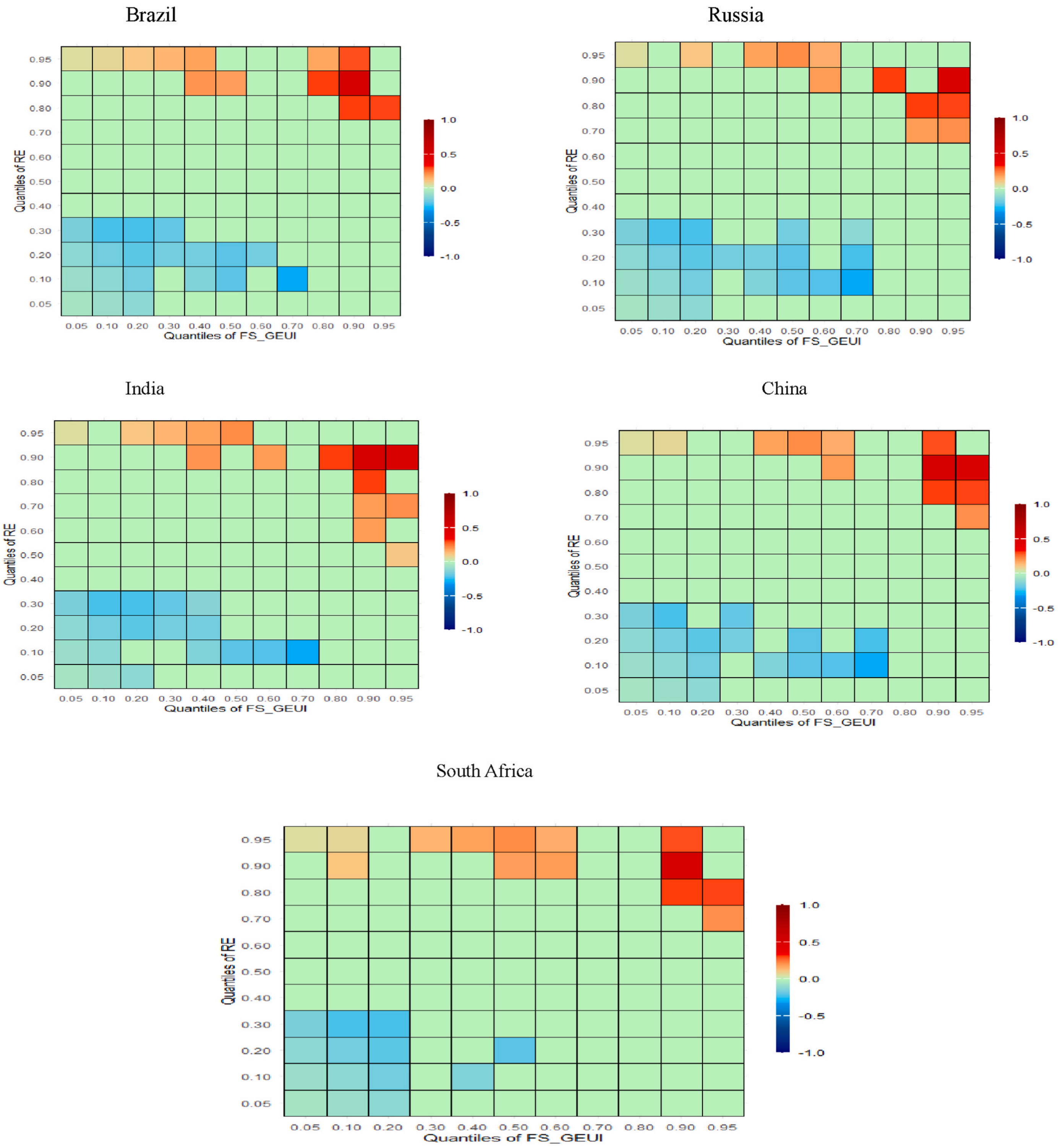


Fig. 9B. Partial cross-quantile correlation between FS and RE in BRICS economies. The control variable is geopolitical risk. The scale presents the intensity and the direction of variables.


Brazil

Russia

India

China

South Africa

Fig. 9C. Partial cross-quantile correlation between FS and RE in BRICS economies. The control variable is global energy uncertainty. The scale presents the intensity and the direction of variables.

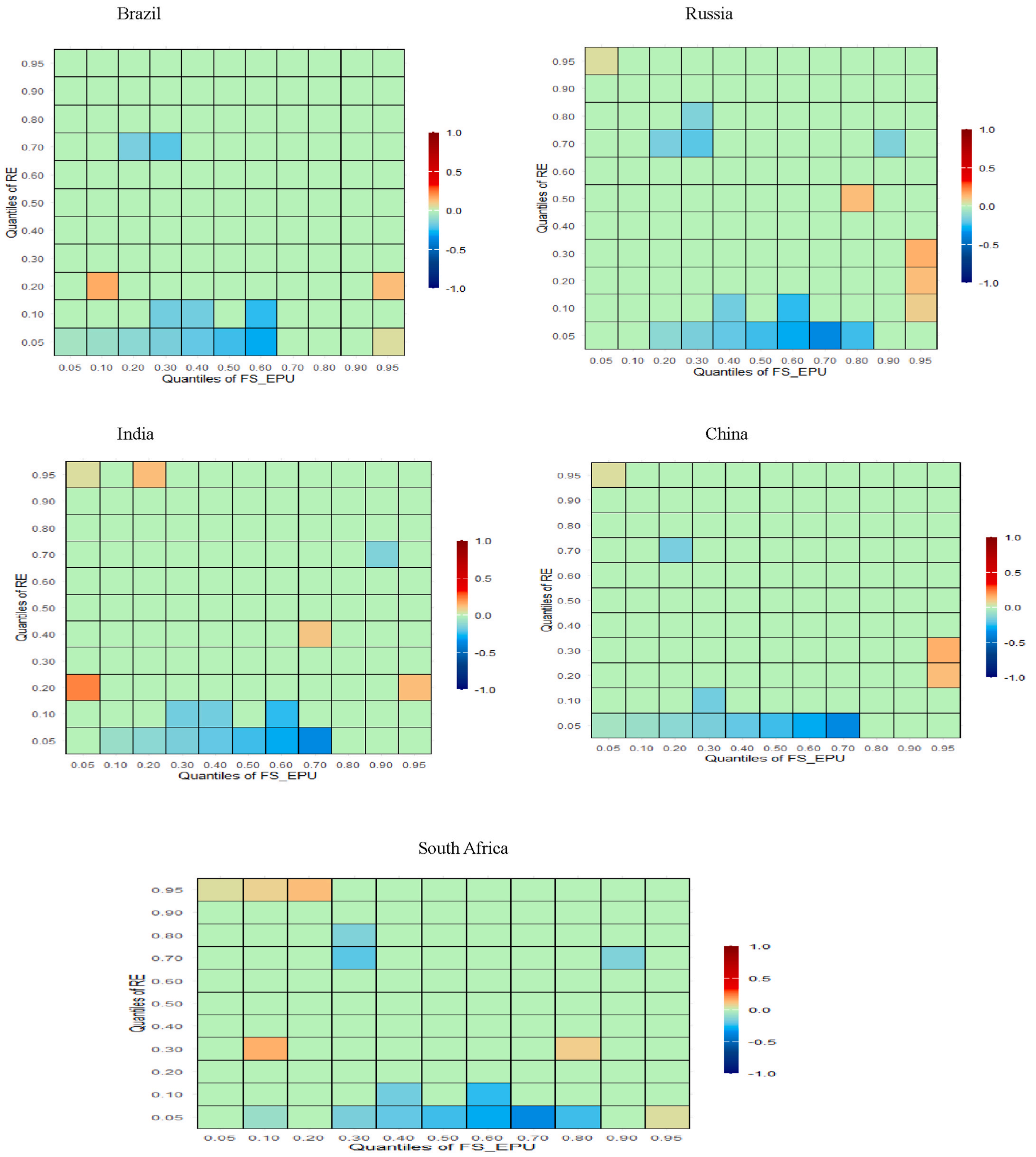


Fig. 9D. Partial cross-quantile correlation between FS and RE in BRICS economies. The control variable is global economic policy uncertainty. The scale presents the intensity and the direction of variables.

effect of FS on RE is quite different across quantiles for BQQ and MQQR. However, the impact of market stress on RE is quite strong at the extreme quantile in the case of MQQR as compare to BQQ. This suggest that market stress plays driving role for RE investment in BRICS economies. These results are robust to QQGC we employed. The QQR show that at the bullish market condition for China, India and South Africa FS adversely affect RE and a mix of positively and negatively related at the upper quantile. In contrast to MQQR which display a mix of positive and negative across quantile indicating the heterogenous effect of FS on RE. The results of the bivariate and multivariate wavelet coherence explicate a strong correlation between RE and FS in the short term and long term to long term. Overall the results show consistent across MQQR, QQGC and wavelet coherence. These findings contribute to understanding the asymmetric effect of market stress and its complex influence market on RE shedding light on the intricate dynamic between the nexus. In view of the above finding, we offer the following recommendation: Our findings emphasize the importance of considering broader market conditions when investing in renewable energy (RE). This is particularly relevant for market participants and investors. For policymakers, our results highlight the need to maintain a stable financial environment in order to attract RE investment in support of efforts and commitments made by international agreements such as the Paris Agreement and the Kyoto Protocol to mitigate and minimize greenhouse gas emission. Our findings reveal that financial stress can hamper the pace of RE development; therefore, policymakers should develop strategies to ease tensions in times of financial distress. For instance, fiscal measures such as quantitative easing, tax cuts, and public spending can be effective in easing a difficult financial situation. Furthermore, the positive effect of financial stress on RE during normal market conditions underscores the need for policymakers to bear the responsibility of safeguarding financial stability as a cornerstone of their mandate. They must employ prudent measures and policy frameworks that mitigate the vulnerabilities and risks inherent in the financial system, ensuring its resilience in the face of shocks and disturbances. The adoption of renewable energy as a substitute for traditional fossil fuels can be a cost-saving strategy for energy users. Therefore, regulatory authorities should monitor prices and competition effectively in the energy market, particularly during times of financial stress, and introduce various stimulus programs such as subsidies and tax holidays to increase demand for RE. In terms of sustainability, our findings highlight the importance of maintaining financial stability to promote the sustainability of the green market.

From the scalogram in Fig. 8 when FS leads RE, that is a nagative shock in FS precedes a decline in investment, In this suitation policymakers should implement proactive measure such as green bonds, or fiscal incentives to stabilize RE investment flows. Conversely if RE preceds FS it may indicate that economic downturn impacts investor confidence in sustainable project requiring macroeconmic stabilization policies. Evidence from the scalogram for Brazil, we observe that FS lead RE in medium and upper frequency band. This means that changes in financial stability influence RE in both medium and long term for the sustained growth in Brazil RE, hence policy makers should focus on green bond and sustainability-linked financing to shield RE investment from market stress. In the case of Russia we observed that at the middle frequency FS and RE co-moves in opposite direction which suggest that RE project are not sufficiently insulated with market stress. We therefore recommend that within a medium term policy makers should provide tax incentive to attract investors in RE sectors. The directional arrows for South Africa suggest that RE investment is sensitive to market stress within medium and upper frequency band, therefore policy makers should blend finance models, to reduce perceived risk in RE projects. In the case of China and India we notice that RE lags behind FS which implies that market stress constraint RE funding availability hence policymakers should encourage financial institutions to lend to the sector during market uncertainties.

BRICS economies have larger and more structure RE market but remain sensitive to market stress. While they outperformed many developed economies in RE investment, they hold-up market stress during systemic risk. Strengthen green financing and improving policy stability during market stress will be crucial for long term RE amid financial market turbulence. By aligning the policy measure with our findings, BRICS economies can built resilent RE sectors that remain stable during systemic risk and continue progressing toward their sustainability goals. While our research provides valuable insights, we acknowledge its limitations. One of the main limitations that we focus on macroeconomic variables in constructing stress index and the potential biases from data interpolation for RE. Future studies should look at FS and specific types of RE(eg wind solar hydro etc). In addition, our research focuses exclusively on BRICS economies making it less directly application to other emerging markets. Future studies are endeavours to extend our research to other emerging economies using different market stress indices.

Funding

The authors declare that this research received no external funding.

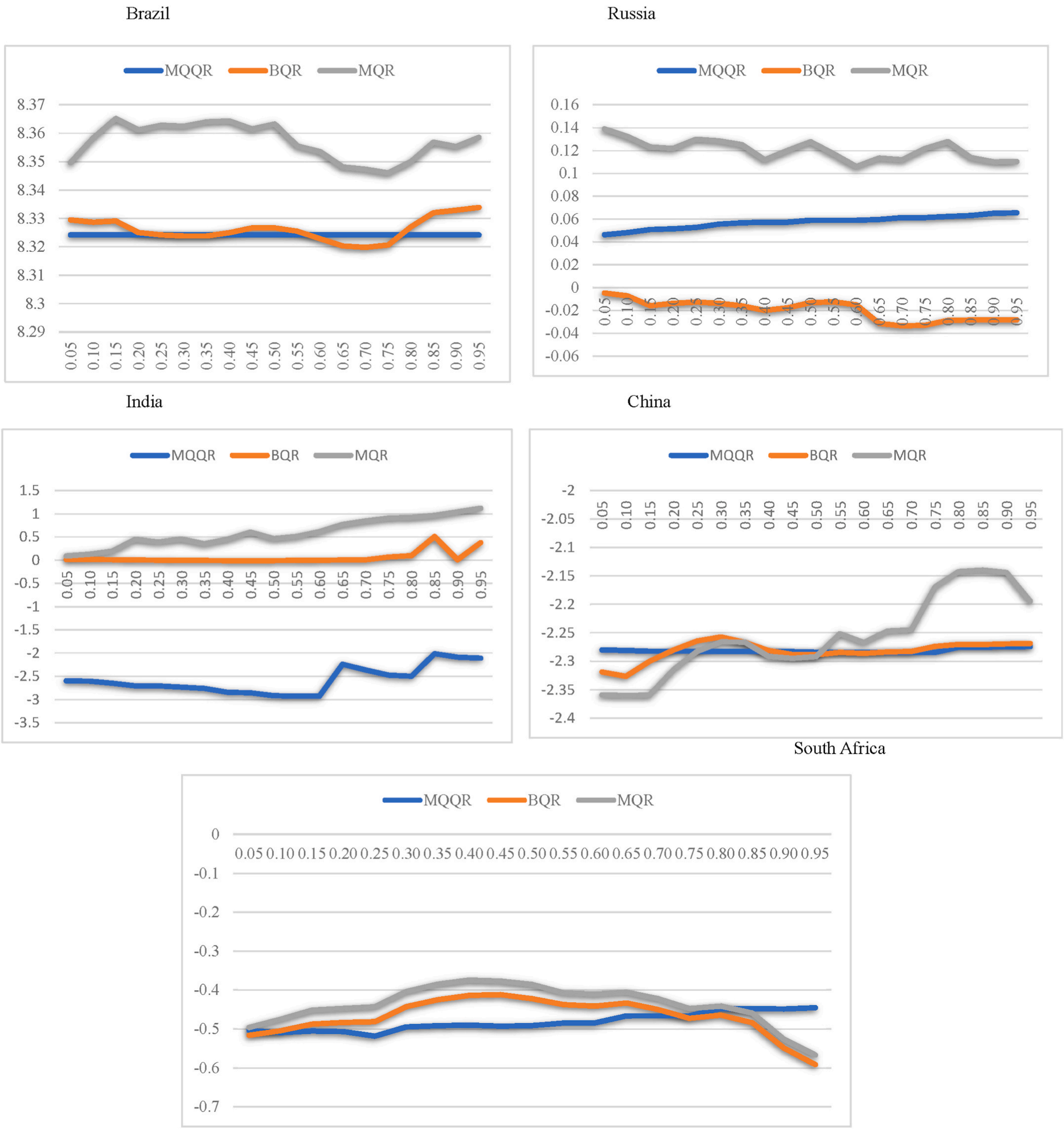
CRediT authorship contribution statement

Mohammed Armah: Conceptualization, Validation, Formal analysis, Data curation, Writing – original draft, Writing – review & editing, Investigation, Visualization, Software, Methodology, Resources. **Ebenezer Bugri Anarfo:** Validation, Visualization, Writing – review & editing, Supervision, Resources. **Emmanuel Numapau Gyamfi:** Validation, Visualization, Writing – review & editing, Supervision, Resources. **Godfred Amewu:** Validation, Visualization, Writing – review & editing, Supervision, Resources.

Declaration of competing interest

The authors declared that there were no conflicts of interest.

Annex A.


Brazil

Russia

India

China

South Africa

Fig. 10. Comparison of MQQR, MQR and BQR.

Appendix A. Multiple wavelet coherence

We employ multiple wavelet of Oygur & Unal [145] which is the n-dimensional coherence to examine the intricate between RE and FS. To do so, our model is

$Y_{RE} \leftarrow (X_{FS}\ X_{GEUI}\ X_{GEPO}\ X_{EPU})$

Where Y_{RE} is the renewable energy (dependent variable) and $X_{FS}\ X_{GEUI}\ X_{GEPO}\ X_{EPU}$ (independent variable), the square n dimension of vector wavelet between the regressand and regressors as follows: $MW^2_{yRE(X_{FS}\ X_{GEUI}\ X_{GEPO}\ X_{EPU})} = MW^2_{yRE(q)} = 1 - \frac{V^d}{K_{yy}V^d_{yy}}$. Here V is 4 × 4 matrix of all smoothed cross-wavelet spectra S_{ij} which denotes the smoothened from of W_{ij} such that $S_{ij} = S(W_{ij})$, Where S is an intended smoothing operator matrix is given as follows;

$$v = \begin{pmatrix} S_{11} & S_{12} & S_{13} \dots & S_{1n} \\ S_{21} & S_{22} & S_{23} \dots & S_{2n} \\ S_{31} & S_{32} & S_{33} \dots & S_{3n} \\ \dots & \dots & \dots & \dots \\ S_{n1} & S_{n2} & S_{n3} \quad \dots & S_{nn} \end{pmatrix} \tag{A.1}$$

Where the v denotes Hermittan matrix. i.e., $v = v^h$ with the symbol h depicting conjugate transpose were $S_{ij} = S^*_{ji}$ for all $i \neq j$ and $S_{ii} = S\left(|w_i|^2\right)$ is the real(positive) number for all i.

The co-factor of the element in position $(i,j)$of v is represented by $v^d_{i,j}v^d_{i,j} = (-1)^{(i+j)}$ *det* $v^j_{i,}$ Where $v^j_{i,}$ is the sub-matrix generated from v after its i^{th} row and j^{th} column; $v^d = \det p$. To describe the v matrix, we may now consider the matrix C, which comprises all smoothed complex wavelet coherence as follows:

$$C = \begin{pmatrix} 1 & \rho_{12} & \rho_{13} \dots & \rho_{1n} \\ \rho_{21} & 1 & \rho_{23} \dots & \rho_{2n} \\ \rho_{31} & \rho_{32} & \rho_{33} \dots & \rho_{3n} \\ \dots & \dots & \dots & \dots \\ \rho_{n1} & \rho_{n2} & \rho_{n3} \quad \dots & \rho_{nn} \end{pmatrix} \tag{A.2}$$

It is important to note that, $\rho_{jj} = \frac{s(w_{jj})}{\sqrt{\left(s\left(|w_j|^2\right)s\left(|w_j|^2\right)\right)}} = \left(\frac{s\left(|w_j|^2\right)}{\left(s\left(|w_j|^2\right)\right.}\right. = 1$. The matrix C is the same as the matrix v (Hermittan), so $\rho_{ij} = \rho^*_{ij}$. Finally, vector coherence in the “n” dimension is defined as follow: $pr^2_{1(q)} = 1 - \frac{C^d}{C^d_{yy}}$. Where C is the 4 × 4 of the smoothed wavelet coherence

Appendix B

Following Han et al. [155,156], we present CQ as follows; Let $q_{1,t}(\tau_1)$ be a τ_1 unconditional quantile of $y_{1,t}$ for i=1,2. The CQ measure dependence between two event $y_{1t} \leq q_{,1t-z}(\tau_1)$ and $y_{2,t-k} \leq q_{2t-z}(\tau_2)$ for arbitrary pair of $\tau = (\tau_1, \tau_2)$ and integral k. For the indicator function 1(·),1 $\left\{y_{1t-z} \leq q_{1,t-k}(\tau_1)\right\}$ shows whether y_{it} located below its τ_i quantile or not. Therefore, the sequence $\left[1\ y_{it} \leq q_{it}(\tau_1)\right\}$ is called the quantile hit. The cross quantilogram is defined as follows:

$$\rho_\tau(k) = \frac{S\left[\psi_{\tau 1}\left(y_{1,t-}q_{1,t}(\tau_1)\right)\psi_{\tau 2}\left(y_{2,t-k} - q_{2,t-k}(\tau_2)\right)\right]}{\sqrt{S\left[\psi^2_{\tau 1}\left(y_{1,t-}q_{1,t}(\tau_1)\right)\sqrt{S\left[\psi^2_{\tau 1}\left(y_{2,t-}q_{2,t-k}(\tau_2)\right)\right]}\right.}} \tag{B.1}$$

For $k = 0, \pm 1, 2, \dots$, where $\psi_{\tau 1}\left(y_{i,t-}q_{1,t}(\tau_1)\right) = 1\left(y_{i,t-k} - q_{i,t-k}(\tau_1)\right) - \tau_1$ its ample counterpart is as follows

$$\widehat{\rho}_\tau(k) = \frac{\sum_{t=k+1}^{T}\psi_{\tau 1}\left(y_{1,t-}\widehat{q}_{1,t}(\tau_1)\right)\psi_{\tau 2}\left(y_{2,t-k} - \widehat{q}_{2,t-k}(\tau_2)\right)\Big]}{\sqrt{\sum_{t=k+1}^{T}\psi^2_{\tau 1}\left(y_{1,t-}\widehat{q}_{1,t}(\tau_1)\right)\sqrt{\sum_{t=k+1}^{T}\psi^2_{\tau 2}\left(y_{2,t-}q_{2,t-k}(\tau_2)\right)\Big]}}} \tag{B.2}$$

In this context, $\widehat{q}_{1,t}(\tau_1)$ denotes the estimator of (τ_1), which may be either conditional or unconditional. We also apply the concepts of partial cross qunatilogram(PCQ) and include uncertanities in accordance with Han et al. [155,156].In instigate the control for the influence of RE and uncertanities on the PCQ between the pair series. Following Han et al. [155,156], we define PCQ as follows as: $Z_t \equiv \left(\left(\psi\left(y_{\tau_3}\left(y_{3t} - q_{3,t}\tau_3\right)\right)\right.\right.$, …., $\left(\left(\psi\left(y_{\tau_3}\left(y_{3t} - q_{3,t}\tau_3\right)\right)\right)'$, Where *l*=*3, 2,.. n* we express the matrix of correlations which is transposed in the following form; $\rho^{-1}_\tau = N[h_t(\check{\tau})h((\check{\tau})'']' = \Gamma_t$ Where $h_t(\check{\tau})$ depict a vector of the quantile hit process and it is expressed as follows: $h_t((\check{\tau}) = ((\psi(y_{1t}(y_{1t} - q_{1t}(\tau_1)), \dots, (\psi_{\tau l}(y_{lt} - q_{lt}(\tau_1))$ Where $P\check{\tau}$ is given by the following as follows:

$p_{\check{\tau}|z} = \frac{p_{\check{\tau}12}}{\sqrt{p_{\check{\tau}11}p_{\check{\tau}12}}}$ Where $p_{\check{\tau}|z}$ denote CQ conditioning on the control of the global financial condition and uncertainties. The $p_{\check{\tau}|z}$ is defined as follows: $p_{\check{\tau}|z} = \varrho\sqrt{\frac{\tau_1(1-\tau_1)}{\tau_2(1-\tau_2)}}$, Where ϱ is defined as the scalar obtained from the following regression: $\psi((y_{1t} - q_{1t}\tau_1)), \dots, \varrho\psi\left(\left(y_{2t} - q_{2,t}\tau_2\right)\right) + y'z_t + u_t$. Where z is the global financial condition and uncertainties for the PCQ.

Data availability

Data will be made available on request.

References

[1] A. Shimbar, S.B. Ebrahimi, Political risk and valuation of renewable energy investments in developing countries, Renew. Energy 145 (2020) 1325–1333, https://doi.org/10.1016/j.renene.2019.06.055.
[2] P.K. Ozili, E. Ozen, Global energy crisis: impact on the global economy, The Impact of Climate Change and Sustainability Standards on the Insurance Market (2023) 439–454.
[3] X. Yang, L. He, Z. Zhong, D. Wang, How does China's green institutional environment affect renewable energy investments? The nonlinear perspective, Sci. Total Environ. 727 (2020) 138689.
[4] C.W. Lee, J. Zhong, Top down strategy for renewable energy investment: conceptual framework and implementation, Renew. Energy 68 (2014) 761–773.
[5] M. Armah, G. Amewu, A. Bossman, Time-frequency analysis of financial stress and global commodities prices : insights from wavelet- based approaches, Cogent Economics & Finance 10 (1) (2022), https://doi.org/10.1080/23322039.2022.2114161.
[6] M. Armah, A. Bossman, G. Amewu, Information flow between global financial market stress and African equity markets: an eemd-based transfer entropy analysis, Heliyon 9 (3) (2023) e13899, https://doi.org/10.2139/ssrn.4269772.
[7] M. Armah, G. Amewu, Time-frequency dynamics of financial market stress and global economic uncertainties : evidence from the COVID-19 pandemic uncertainties : evidence from the COVID-19 pandemic, Appl. Econ. Lett. (2022) 1–6, https://doi.org/10.1080/13504851.2022.2156465, 00(00.
[8] M. Alomari, R. Selmi, W. Mensi, H.-U. Ko, S.H. Kang, Dynamic spillovers in higher moments and jumps across ETFs and economic and financial uncertainty factors in the context of successive shocks, Q. Rev. Econ. Finance (2023), https://doi.org/10.1016/j.qref.2023.12.009.
[9] A. Sinha, V. Ghosh, N. Hussain, D.K. Nguyen, N. Das, Green financing of renewable energy generation: capturing the role of exogenous moderation for ensuring sustainable development, Energy Econ. 126 (June) (2023) 107021, https://doi.org/10.1016/j.eneco.2023.107021.
[10] M.D. Miah, M. Shafiullah, M.S. Alam, The effect of financial stress on renewable energy consumption: evidence from US data, Environ. Dev. Sustain. (2023) 1–24.
[11] C. Sun, A. Khan, Y. Liu, N. Lei, An analysis of the impact of fiscal and monetary policy fluctuations on the disaggregated level renewable energy generation in the G7 countries, Renew. Energy 189 (2022) 1154–1165, https://doi.org/10.1016/j.renene.2022.03.027.
[12] C.S. Hakkio, W.R. Keeton, Financial stress: what is it, how can it be measured, and why does it matter? Economic Review 94 (2) (2009) 5–50, https://doi.org/10.2469/dig.v40.n1.29.
[13] A.H. Elsayed, L. Yarovaya, Financial stress dynamics in the MENA region: evidence from the Arab Spring, J. Int. Financ. Mark. Inst. Money 62 (2019) 20–34, https://doi.org/10.1016/j.intfin.2019.05.004.
[14] M. Shafiullah, M.D. Miah, M.S. Alam, M. Atif, Does economic policy uncertainty affect renewable energy consumption? Renew. Energy 179 (2021) 1500–1521, https://doi.org/10.1016/j.renene.2021.07.092.
[15] P. Schwabe, K. Cory, J. Newcomb, Renewable Energy Project Financing: Impacts of the Financial Crisis and Federal Legislation, National Renewable Energy Lab. (NREL), Golden, CO (United States), 2009.
[16] D.M. Hofman, R. Huisman, Did the financial crisis lead to changes in private equity investor preferences regarding renewable energy and climate policies? Energy Policy 47 (2012) 111–116.
[17] N.I. Meyer, A.L. Koefoed, Danish energy reform: policy implications for renewables, Energy Policy 31 (7) (2003) 597–607.
[18] L. Byrnes, C. Brown, J. Foster, L.D. Wagner, Australian renewable energy policy: barriers and challenges, Renew. Energy 60 (2013) 711–721.
[19] T. Nelson, J. Nelson, J. Ariyaratnam, S. Camroux, An analysis of Australia's large scale renewable energy target: restoring market confidence, Energy Policy 62 (2013) 386–400, https://doi.org/10.1016/j.enpol.2013.07.096.
[20] W. White, A. Lunnan, E. Nybakk, B. Kulisic, The role of governments in renewable energy: the importance of policy consistency, Biomass Bioenergy 57 (2013) 97–105, https://doi.org/10.1016/j.biombioe.2012.12.035.
[21] A.G. Olabi, M.A. Abdelkareem, Renewable energy and climate change, Renew. Sustain. Energy Rev. 158 (2022) 112111.
[22] F. Morina, U. Ergün, E. Hysa, Understanding drivers of renewable energy firm's performance, Environ. Res. Eng. Manag. 77 (3) (2021) 32–49, https://doi.org/10.5755/j01.erem.77.3.29230.
[23] V. Khare, A. Jain, M.A. Bhuiyan, Perspective of renewable energy in the BRICS country, E-Prime - Advances in Electrical Engineering, Electronics and Energy 5 (July) (2023) 100250, https://doi.org/10.1016/j.prime.2023.100250.
[24] V. Khare, S. Nema, P. Baredar, Optimisation of the hybrid renewable energy system by HOMER, PSO and CPSO for the study area, Int. J. Sustain. Energy 36 (4) (2017) 326–343.
[25] K. Dong, X. Dong, Q. Jiang, How renewable energy consumption lower global CO2 emissions? Evidence from countries with different income levels, World Econ. 43 (6) (2020) 1665–1698.
[26] D. Gielen, R. Gorini, N. Wagner, R. Leme, L. Gutierrez, G. Prakash, E. Asmelash, L. Janeiro, G. Gallina, G. Vale, Global Energy Transformation: a Roadmap to 2050, 2019.
[27] B. Gaies, N. Chaâbane, The dance of dependence: a macro-perspective on financial instability and its complex influence on the Euro-American green markets, J. Econ. Stud. 51 (2023) 546–568.
[28] A. Tsagkanos, D. Argyropoulou, G. Androulakis, Asymmetric economic effects via the dependence structure of green bonds and financial stress index, J. Econ. Asymmetries 26 (2022) e00264.
[29] G.N. Apostolakis, C. Floros, K. Gkillas, M. Wohar, Political uncertainty, COVID-19 pandemic and stock market volatility transmission, J. Int. Financ. Mark. Inst. Money 74 (2021) 101383.
[30] R. Ferrer, R. Jammazi, V.J. Bolós, R. Benítez, Interactions between financial stress and economic activity for the US: a time-and frequency-varying analysis using wavelets, Phys. Stat. Mech. Appl. 492 (2018) 446–462.
[31] M.T. Majeed, Z. Hussain, Financial sector development and renewable energy consumption nexus: evidence from global dynamic panel threshold analysis, Nat. Resour. Forum (2023).
[32] D. Wei, H. Wu, Impact of financial development on the development of the renewable energy industry of China, Journal of Climate Finance 5 (2023) 100023.
[33] B. Hu, A.A. Alola, M.Z. Tauni, T.S. Adebayo, S. Abbas, Pathway to cleaner environment: how effective are renewable electricity and financial development approaches? Struct. Change Econ. Dynam. 67 (March) (2023) 277–292, https://doi.org/10.1016/j.strueco.2023.08.003.
[34] S.A. Athari, The impact of financial development and technological innovations on renewable energy consumption: do the roles of economic openness and financial stability matter in BRICS economies? Geol. J. 59 (2023) 288–300.
[35] S. Diallo, Y. Ouoba, Financial development and renewable energy deployment in sub-saharan African countries, Int. J. Energy Sect. Manag. 18 (2023) 1305–1327.
[36] K. Saidi, Does financial development and renewable energy matter for economic development? A study of emerging economies, J. Knowl. Econ. (2023) 1–17.
[37] S. Mukhtarov, J.I. Mikayilov, Could financial development eliminate energy poverty through renewable energy in Poland? Energy Policy 182 (2023) 113747.
[38] S.K. Dimnwobi, C.V. Madichie, C. Ekesiobi, S.A. Asongu, Financial development and renewable energy consumption in Nigeria, Renew. Energy 192 (2022) 668–677.
[39] U. Habiba, C. Xinbang, The contribution of different aspects of financial development to renewable energy consumption in E7 countries: the transition to a sustainable future, Renew. Energy 203 (2023) 703–714.
[40] S. Yi, C. Raghutla, K.R. Chittedi, Z. Fareed, How economic policy uncertainty and financial development contribute to renewable energy consumption? The importance of economic globalization, Renew. Energy 202 (2023) 1357–1367.
[41] M.Z. Chishti, E. Dogan, Analyzing the determinants of renewable energy: the moderating role of technology and macroeconomic uncertainty, Energy Environ. (2022) 0958305X221137567.
[42] K. Khan, C.W. Su, Does policy uncertainty threaten renewable energy? Evidence from G7 countries, Environ. Sci. Pollut. Control Ser. 29 (23) (2022) 34813–34829.
[43] I. Dokas, G. Oikonomou, M. Panagiotidis, E. Spyromitros, Macroeconomic and uncertainty shocks' effects on energy prices: a comprehensive literature review, Energies 16 (3) (2023) 1491.
[44] C. Liang, M. Umar, F. Ma, T.L.D. Huynh, Climate policy uncertainty and world renewable energy index volatility forecasting, Technol. Forecast. Soc. Change 182 (2022) 121810, https://doi.org/10.1016/j.techfore.2022.121810.
[45] S. Li, H. Sun, A. Sharif, M. Bashir, M.F. Bashir, Economic complexity, natural resource abundance and education: implications for sustainable development in BRICST economies, Resour. Policy 89 (2024) 104572, https://doi.org/10.1016/j.resourpol.2023.104572.
[46] O.S. Ojekemi, M. Ağa, C. Magazzino, Towards achieving sustainability in the BRICS economies: the role of renewable energy consumption and economic risk, Energies 16 (14) (2023) 5287.
[47] M.M. Alam, M.A. Destek, A. Haque, D. Kirikkaleli, S. Pinzón, K. Khudoykulov, Can undergoing renewable energy transition assist the BRICS countries in achieving environmental sustainability? Environ. Sci. Pollut. Control Ser. (2024) 1–13.
[48] M. Simonova, V.E. Zakharov, I. Mamiy, Prospects of renewable energy sources: the case study of the BRICS countries, Int. J. Energy Econ. Pol. 9 (5) (2019) 186–193.
[49] V.E. Zakharov, M.D. Simonova, Green energy of the BRICS countries: the driver of inclusive development, in: Current Problems of the Global Environmental Economy Under the Conditions of Climate Change and the Perspectives of Sustainable Development, Springer, 2023, pp. 323–336.
[50] J. Guo, X. Li, Y. Mu, F. Zhao, L. Wu, H. Yang, A compound accumulation grey model and its prediction of new energy generation in BRICS countries, Energy Strategy Rev. 50 (2023) 101221.
[51] M. Armah, G. Amewu, Quantile dependence and asymmetric connectedness between global financial market stress and REIT returns : evidence from the COVID-19 pandemic, J. Econ. Asymmetries 29 (January) (2024) e00352, https://doi.org/10.1016/j.jeca.2024.e00352.
[52] M. Balcilar, A.H. Elsayed, S. Hammoudeh, Financial connectedness and risk transmission among MENA countries: evidence from connectedness network and clustering analysis, J. Int. Financ. Mark. Inst. Money 82 (2023) 101656, https://doi.org/10.1016/j.intfin.2022.101656.
[53] B. Ma, A. Sharif, M. Bashir, M.F. Bashir, The dynamic influence of energy consumption, fiscal policy and green innovation on environmental degradation in BRICST economies, Energy Policy 183 (2023) 113823, https://doi.org/10.1016/j.enpol.2023.113823.
[54] S. Li, M.Z. Tauni, S. Afshan, X. Dong, S. Abbas, Moving towards a sustainable environment in the BRICS economies: what are the effects of financial

development, renewable energy and natural resources within the LCC hypothesis? Resour. Policy 88 (2024) 104457.
[55] E.J.A. Abakah, M. Abdullah, I. Yousaf, A. Kumar Tiwari, Y. Li, Economic sanctions sentiment and global stock markets, J. Int. Financ. Mark. Inst. Money 91 (2024) 101910, https://doi.org/10.1016/j.intfin.2023.101910.
[56] G.N. Apostolakis, N. Giannellis, Monetary policy and uncertainty spillovers: evidence from a wavelet and frequency connectedness analysis, Int. Rev. Financ. Anal. 95 (2024) 103513.
[57] L.H. Sendstad, V. Hagspiel, W.J. Mikkelsen, R. Ravndal, M. Tveitstøl, The impact of subsidy retraction on European renewable energy investments, Energy Policy 160 (2022) 112675, https://doi.org/10.1016/j.enpol.2021.112675.
[58] P.T.-H. Cao, D.H. Vo, Market responses to geopolitical risk and economic policy uncertainty: evidence from Vietnam, Heliyon (2025) e42703.
[59] F. Wang, W. Zhang, D. Zhang, The time-varying impact of geopolitical risks on financial stress in China: a TVP-VAR analysis, Finance Res. Lett. 69 (2024) 106134.
[60] N. Sim, H. Zhou, Oil prices, US stock return, and the dependence between their quantiles, J. Bank. Finance 55 (January) (2015) 1–8, https://doi.org/10.1016/j.jbankfin.2015.01.013.
[61] O. Ozkan, R.A. Haruna, A.A. Alola, W. Ghardallou, O. Usman, Investigating the nexus between economic complexity and energy-related environmental risks in the USA: empirical evidence from a novel multivariate quantile-on-quantile regression, Struct. Change Econ. Dynam. 65 (January) (2023) 382–392, https://doi.org/10.1016/j.strueco.2023.03.010.
[62] O. Usman, P.T. Iorember, O. Ozkan, A.A. Alola, Dampening energy security-related uncertainties in the United States: the role of green energy-technology investment and operation of transnational corporations, Energy 289 (2024) 130006.
[63] B. Ohene Kwatia, G. Amewu, M. Armah, Does personal freedom matter for financial development in Africa? Cogent Economics and Finance 12 (1) (2024) https://doi.org/10.1080/23322039.2024.2355547.
[64] G. Amewu, N.K. Akosah, M. Armah, African sovereign risk premia and international market assets: a relook under the COVID-19 outbreak, Heliyon 10 (21) (2024) e40194, https://doi.org/10.1016/j.heliyon.2024.e40194.
[65] G. Amewu, M. Armah, S. Kuttu, B.A. Kusi, African and international financial markets interdependencies: does Covid-19 media coverage make any difference? Research in Globalization (2024) 100249.
[66] U.A. Muller, M.M. Dacorogna, R.D. Dav, B. Olsen, O.V. Pictet, Volatilities of different time resolutions - analyzing the dynamics of market components, J. Empir. Finance 4 (2–3) (1997) 213–239.
[67] J.B. De Long, A. Shleifer, L.H. Summers, R.J. Waldmann, Noise trader risk in financial markets, J. Polit. Econ. 98 (4) (1990) 703–738.
[68] A.O. Acheampong, S. Adams, E. Boateng, Do globalization and renewable energy contribute to carbon emissions mitigation in Sub-Saharan Africa? Sci. Total Environ. 677 (2019) 436–446.
[69] Y. Zhang, M. Qamruzzaman, S. Karim, I. Jahan, Nexus between economic policy uncertainty and renewable energy consumption in BRIC nations: the mediating role of foreign direct investment and financial development, Energies 14 (15) (2021) 4687.
[70] E.C. Arbatli, Economic Policies and FDI Inflows to Emerging Market Economies, 2011.
[71] Y. Yuan, H. Wang, X. Jin, Pandemic-driven financial contagion and investor behavior: evidence from the COVID-19, Int. Rev. Financ. Anal. 83 (2022) 102315.
[72] T. Akan, Can renewable energy mitigate the impacts of inflation and policy interest on climate change? Renew. Energy. 214 (2023) 255–289.
[73] J. Chen, X. Luo, Q. Ding, Climate risk and renewable energy technological innovation: an institutional environment perspective, Risk Anal. 44 (2023) 566–581.
[74] S.M. Hashmi, Q.R. Syed, R. Inglesi-Lotz, Monetary and energy policy interlinkages: the case of renewable energy in the US, Renew. Energy 201 (P1) (2022) 141–147, https://doi.org/10.1016/j.renene.2022.10.082.
[75] S. Juhola, A. Laurila, F. Groundstroem, J. Klein, Climate risks to the renewable energy sector: assessment and adaptation within energy companies, Bus. Strat. Environ. 33 (2023) 1906–1919.
[76] K. Khan, C.W. Su, A. Khurshid, M. Qin, Does energy security improve renewable energy? A geopolitical perspective, Energy (2023) 128824, https://doi.org/10.1016/j.energy.2023.128824.
[77] C.-C. Lee, Z. Yuan, C.-C. Lee, Y.-F. Chang, The impact of renewable energy technology innovation on energy poverty: does climate risk matter? Energy Econ. 116 (2022) 106427.
[78] S.F. Razmi, M.H. Moghadam, M. Behname, Time-varying effects of monetary policy on Iranian renewable energy generation, Renew. Energy 177 (2021) 1161–1169, https://doi.org/10.1016/j.renene.2021.06.020.
[79] O.O. Yolcan, World energy outlook and state of renewable energy: 10-year evaluation, Innov. Green Dev. 2 (4) (2023) 100070.
[80] Z. Zhao, G. Gozgor, M.C.K. Lau, M.K. Mahalik, G. Patel, R. Khalfaoui, The impact of geopolitical risks on renewable energy demand in OECD countries, Energy Econ. 122 (2023) 106700, https://doi.org/10.1016/j.eneco.2023.106700.
[81] M. Ahmad, E. Satrovic, How does monetary policy moderate the influence of economic complexity and technological innovation on environmental sustainability? The role of green central banking, Int. J. Finance Econ. 29 (2023) 4197–4224.
[82] M. Jamil, F. Ahmed, G.C. Debnath, Š. Bojnec, Transition to renewable energy production in the United States: the role of monetary, fiscal, and trade policy uncertainty, Energies 15 (13) (2022) 4527.
[83] M. Shahbaz, B.A. Topcu, S.S. Sarıgül, X.V. Vo, The effect of financial development on renewable energy demand: the case of developing countries, Renew. Energy 178 (2021) 1370–1380, https://doi.org/10.1016/j.renene.2021.06.121.
[84] J. Wang, S. Zhang, Q. Zhang, The relationship of renewable energy consumption to financial development and economic growth in China, Renew. Energy 170 (2021) 897–904.
[85] U.K. Pata, A.A. Alola, S. Erdogan, M.T. Kartal, The influence of income, economic policy uncertainty, geopolitical risk, and urbanization on renewable energy investments in G7 countries, Energy Econ. 128 (2023) 107172.
[86] M.Z. Rehman, S. Khan, U.A. Khan, W.B. Alonazi, A.A. Noman, How do global uncertainties spillovers affect leading renewable energy indices? Evidence from the network connectedness approach, Sustainability 15 (18) (2023) 13630.
[87] S. Husain, K. Sohag, Y. Wu, The responsiveness of renewable energy production to geopolitical risks, oil market instability and economic policy uncertainty: evidence from United States, J. Environ. Manag. 350 (April 2022) (2023) 119647, https://doi.org/10.1016/j.jenvman.2023.119647.
[88] F. Farooq, M. Faheem, A. Nousheen, Economic policy uncertainty, renewable energy consumption and environmental sustainability in China, Pakistan Journal of Humanities and Social Sciences 11 (2) (2023) 1978–1993.
[89] F. Durani, R. Bhowmik, A. Sharif, A. Anwar, Q.R. Syed, Role of economic uncertainty, financial development, natural resources, technology, and renewable energy in the environmental phillips curve framework, J. Clean. Prod. 420 (2023) 138334.
[90] J. Ni, J. Ruan, Contagion effects of external monetary shocks on systemic financial risk in China: evidence from the Euro area and Japan, N. Am. J. Econ. Finance 70 (2024) 102055, https://doi.org/10.1016/j.najef.2023.102055.
[91] J. Baruník, T. Křehlík, Measuring the frequency dynamics of financial connectedness and systemic risk, J. Financ. Econom. 16 (2) (2018) 271–296, https://doi.org/10.1093/jjfinec/nby001.
[92] T. Adam, S. Benecká, J. Matějů, Financial stress and its non-linear impact on CEE exchange rates, J. Financ. Stabil. 36 (2018) 346–360, https://doi.org/10.1016/j.jfs.2018.04.008.
[93] B.K. Altınkeski, E.I. Cevik, S. Dibooglu, A.M. Kutan, Financial stress transmission between the U.S. and the Euro Area, J. Financ. Stabil. 60 (March) (2022) 101004, https://doi.org/10.1016/j.jfs.2022.101004.
[94] N. Antonakakis, D. Gabauer, R. Gupta, International monetary policy spillovers: evidence from a time-varying parameter vector autoregression, Int. Rev. Financ. Anal. 65 (July) (2019) 101382, https://doi.org/10.1016/j.irfa.2019.101382.
[95] G. Biglarkhani, J. Beytari, E. Sefidbakht, The effect of macroeconomic indicators on the financial stress index in the members of the organization of the petroleum exporting countries (OPEC) keywords : 2. Theoretical foundations literature review, International Journal of Finance and Managerial Accounting 8 (29) (2023) 195–210.
[96] S. Dajčman, A. Kavkler, P. Mikek, D. Romih, Transmission of financial stress shocks between the USA and the euro area during different business cycle phases, Technická Univerzita v Liberci 23 (4) (2020) 152–165, https://doi.org/10.15240/tul/001/2020-4-010.
[97] S. Dajčman, A. Kavkler, S. Merzlyakov, S.E. Pekarski, D. Romih, International transmission of conventional and unconventional monetary policy and financial stress shocks from the Euro area to Russia, J. Cent. Bank Theor. Pract. 11 (1) (2022) 227–247, https://doi.org/10.2478/jcbtp-2022-0010.
[98] D. Zhang, M. Yan, A. Tsopanakis, Financial stress relationships among Euro area countries: an R-vine copula approach, Eur. J. Finance 24 (17) (2018) 1587–1608, https://doi.org/10.1080/1351847X.2017.1419273.
[99] X. He, S. Mishra, A. Aman, M. Shahbaz, A. Razzaq, A. Sharif, The linkage between clean energy stocks and the fluctuations in oil price and financial stress in the US and Europe? Evidence from QARDL approach, Resour. Policy 72 (September 2020) (2021) 102021, https://doi.org/10.1016/j.resourpol.2021.102021.
[100] S. Wahab, M. Imran, A. Safi, Z. Wahab, D. Kirikkaleli, Role of financial stability, technological innovation, and renewable energy in achieving sustainable development goals in BRICS countries, Environ. Sci. Pollut. Control Ser. 29 (32) (2022) 48827–48838.
[101] Q.K. Nguyen, V.C. Dang, Renewable energy consumption, carbon dioxide emission and financial stability: does institutional quality matter? Appl. Econ. (2023) 1–18.
[102] Y. Dafermos, M. Nikolaidi, G. Galanis, Climate change, financial stability and monetary policy, Ecol. Econ. 152 (May) (2018) 219–234, https://doi.org/10.1016/j.ecolecon.2018.05.011.
[103] A. Safi, S. Wahab, F. Zeb, M. Amin, Y. Chen, Does financial stability and renewable energy promote sustainable environment in G-7 countries? The role of income and international trade, Environ. Sci. Pollut. Control Ser. 28 (34) (2021) 47628–47640.
[104] Q. Wang, C. Zhang, R. Li, Impact of different geopolitical factors on the energy transition: the role of geopolitical threats, geopolitical acts, and geopolitical risks, J. Environ. Manag. 352 (2024) 119962.
[105] Q. Wang, Y. Li, R. Li, Integrating artificial intelligence in energy transition: a comprehensive review, Energy Strategy Rev. 57 (2025) 101600.
[106] Q. Wang, T. Sun, R. Li, Does Artificial Intelligence (AI) enhance green economy efficiency? The role of green finance, trade openness, and R&D investment, Humanit. Soc. Sci. Commun. 12 (1) (2025) 1–22.
[107] R. Koenker, Jr G. Bassett, Regression quantiles, Econometrica: J. Econom. Soc. (1978) 33–50.
[108] J. Yang, S.K. Agyei, A. Bossman, M. Gubareva, E. Marfo-yiadom, Energy, metals, market uncertainties, and ESG stocks: analysing predictability and safe havens, N. Am. J. Econ. Finance (2023) 102030., https://doi.org/10.1016/j.najef.2023.102030.

[109] A.A. Alola, O. Özkan, O. Usman, Examining crude oil price outlook amidst substitute energy price and household energy expenditure in the USA: a novel nonparametric multivariate QQR approach, Energy Econ. 120 (2023) 106613.
[110] L. Aguiar-Conraria, N. Azevedo, M.J. Soares, Using wavelets to decompose the time–frequency effects of monetary policy, Phys. Stat. Mech. Appl. 387 (12) (2008) 2863–2878.
[111] I. Daubechies, Ten Lectures on Wavelets, SIAM, 1992.
[112] L. Aguiar-Conraria, M.M.F. Martins, M.J. Soares, The yield curve and the macro-economy across time and frequencies, J. Econ. Dynam. Control 36 (12) (2012) 1950–1970, https://doi.org/10.1016/j.jedc.2012.05.008.
[113] S. Mallat, A Wavelet Tour of Signal Processing, Elsevier, 1999.
[114] C. Torrence, J.P. Webster, The annual cycle of persistence in the El Nino/Southern Oscillation, Q. J. R. Meteorol. Soc. 124 (550) (1998) 1985–2004, https://doi.org/10.1256/smsqj.55009.
[115] A. Rua, L.C. Nunes, International comovement of stock market returns: a wavelet analysis, J. Empir. Finance 16 (4) (2009) 632–639, https://doi.org/10.1016/j.jempfin.2009.02.002.
[116] C. Torrence, G.P. Compo, A practical guide to wavelet analysis, Bulletin of America Meterological Society 79 (1998) 61–78.
[117] A.H. Elsayed, N. Naifar, S. Nasreen, Financial stability and monetary policy reaction: evidence from the GCC countries, Q. Rev. Econ. Finance 87 (2023) 396–405, https://doi.org/10.1016/j.qref.2022.03.003.
[118] G.N. Apostolakis, N. Giannellis, A.P. Papadopoulos, Financial stress and asymmetric shocks transmission within the Eurozone. How fragile is the common monetary policy? N. Am. J. Econ. Finance 50 (June) (2019) 101006 https://doi.org/10.1016/j.najef.2019.101006.
[119] R. MacDonald, V. Sogiakas, A. Tsopanakis, Volatility co-movements and spillover effects within the Eurozone economies: a multivariate GARCH approach using the financial stress index, J. Int. Financ. Mark. Inst. Money 52 (2018) 17–36, https://doi.org/10.1016/j.intfin.2017.09.003.
[120] C.Y. Park, R.V. Mercado, Determinants of financial stress in emerging market economies, J. Bank. Finance 45 (1) (2014) 199–224, https://doi.org/10.1016/j.jbankfin.2013.09.018.
[121] R. Balakrishnan, S. Danninger, S. Elekdag, I. Tytell, The transmission of financial stress from advanced to emerging economies, Emerg. Mark. Finance Trade 47 (SUPPL. 2) (2011) 40–68, https://doi.org/10.2753/REE1540-496X4703S203.
[122] S. Mundra, M. Bicchal, Evaluating financial stress indicators: evidence from Indian data, Journal of Financial Economic Policy 13 (1) (2021) 116–135, https://doi.org/10.1108/JFEP-11-2019-0232.
[123] B. Eichengreen, A. Rose, C. Wyplosz, Contagious currency crises, in: B. Eichengreen (Ed.), Capital Flows and Crises, Massachusetts Institute of Technology Press, 2004, https://doi.org/10.1111/1467-8411.00059.
[124] T. Klayme, K.K. Gokmenoglu, B. Rustamov, Economic policy uncertainty, COVID-19 and corporate investment: evidence from the gold mining industry, Resour. Policy 85 (2023) 103787, https://doi.org/10.1016/j.resourpol.2023.103787.
[125] S.A. Al-Thaqeb, B.G. Algharabali, Economic policy uncertainty: a literature review, J. Econ. Asymmetries 20 (2019) e00133.
[126] C. Baumeister, D. Korobilis, T.K. Lee, Energy markets and global economic conditions, Rev. Econ. Stat. 104 (4) (2020) 828–844.
[127] G.V.S. Chiranjivi, R. Sensarma, The effects of economic and financial shocks on private investment: a wavelet study of return and volatility spillovers, Int. Rev. Financ. Anal. 90 (2023) 102936, https://doi.org/10.1016/j.irfa.2023.102936.
[128] F.J. Anscombe, W.J. Glynn, Distribution of the kurtosis statistic b2 for normal samples, Biometrika 70 (1) (1983) 227–234, https://doi.org/10.1093/biomet/70.1.227.
[129] C.M. Jarque, A.K. Bera, Efficient tests for normality, homoscedasticity and serial independence of regression residuals, Econ. Lett. 6 (3) (1980) 255–259, https://doi.org/10.1016/0165-1765(80)90024-5.
[130] Elliott, T.J. Rothenberg, J.H. Stock, Efficient test for an autoregressive unit roots, Econometrica 4 (64) (1996) 813–836.
[131] T.J. Fisher, C.M. Gallagher, New weighted portmanteau statistics for time series goodness of fit testing, J. Am. Stat. Assoc. 107 (498) (2012) 777–787, https://doi.org/10.1080/01621459.2012.688465.
[132] W.A. Broock, J.A. Scheinkman, W.D. Dechert, B. LeBaron, A test for independence based on the correlation dimension, Econom. Rev. 15 (3) (1996) 197–235.
[133] M. Gubareva, A. Bossman, T. Teplova, North American journal of economics and finance stablecoins as the cornerstone in the linkage between the digital and conventional financial markets, N. Am. J. Econ. Finance 68 (February) (2023) 101979, https://doi.org/10.1016/j.najef.2023.101979.
[134] A. Bossman, Z. Umar, T. Teplova, Modelling the asymmetric effect of COVID-19 on REIT returns: a quantile-on-quantile regression analysis, J. Econ. Asymmetries 26 (May) (2022) e00257, https://doi.org/10.1016/j.jeca.2022.e00257.
[135] S.M. Alsubaie, K.H. Mahmoud, A. Bossman, E. Asafo-adjei, Vulnerability of sustainable Islamic stock returns to implied market volatilities : an asymmetric approach, Discrete Dynam Nat. Soc. 2022 (2022) 9–12.
[136] Z. Umar, A. Bossman, S.Y. Choi, T. Teplova, Does geopolitical risk matter for global asset returns? Evidence from quantile-on-quantile regression, Finance Res. Lett. 48 (March) (2022) 102991, https://doi.org/10.1016/j.frl.2022.102991.
[137] M. Balcilar, O. Usman, H. Gungor, D. Roubaud, M.E. Wohar, Role of global, regional, and advanced market economic policy uncertainty on bond spreads in emerging markets, Econ. Modell. 102 (2021) 105576.
[138] M. Balcilar, O. Usman, D. Roubaud, How do energy market shocks affect economic activity in the US under changing financial conditions?, in: Applications in Energy Finance: the Energy Sector, Economic Activity, Financial Markets and the Environment Springer, 2022, pp. 85–114.
[139] T.S. Adebayo, O. Özkan, Evaluating the role of financial globalization and oil consumption on ecological quality: a new perspective from quantile-on-quantile granger causality, Heliyon (2024) e24636.
[140] Q. Wang, F. Zhang, R. Li, J. Sun, Does artificial intelligence promote energy transition and curb carbon emissions? The role of trade openness, J. Clean. Prod. 447 (2024) 141298, https://doi.org/10.1016/j.jclepro.2024.141298.
[141] J. Xiao, F. Wen, Z. He, Impact of geopolitical risks on investor attention and speculation in the oil market: evidence from nonlinear and time-varying analysis, Energy 267 (2023) 126564.
[142] X. Wang, Y. Wu, W. Xu, Geopolitical risk and investment, J. Money Credit Bank. 56 (2019) 2023–2059.
[143] U.A. Müller, M.M. Dacorogna, R.D. Davé, O.V. Pictet, R.B. Olsen, J.R. Ward, Fractals and intrinsic time-a challenge to econometricians, SSRN (2008).
[144] W. Mensi, X.V. Vo, H.U. Ko, S.H. Kang, Frequency spillovers between green bonds, global factors and stock market before and during COVID-19 crisis, Econ. Anal. Pol. 77 (2023) 558–580, https://doi.org/10.1016/j.eap.2022.12.010.
[145] T. Oygur, G. Unal, Vector wavelet coherence for multiple time series, International Journal of Dynamics and Control (July) (2020), https://doi.org/10.1007/s40435-020-00706-y.
[146] S. Husain, K. Sohag, Y. Wu, The responsiveness of renewable energy production to geopolitical risks, oil market instability and economic policy uncertainty: evidence from United States, J. Environ. Manag. 350 (2024) 119647.
[147] P. Jian, S. Zhengjie, Navigating the green future: unraveling the role of fintech, decentralization, natural resources, and monetary policy uncertainty in China, Resour. Policy 89 (2024) 104573.
[148] J.E. Gomez-Gonzalez, J. Hirs-Garzon, J.M. Uribe, US uncertainty shocks on real and financial markets: a multi-country perspective, Econ. Syst. (2024) 101180.
[149] B. Gaies, S. Goutte, K. Guesmi, What interactions between financial globalization and instability?—Growth in developing countries, J. Int. Dev. 31 (1) (2019) 39–79.
[150] R. Ferrer, S.J.H. Shahzad, R. López, F. Jareño, Time and frequency dynamics of connectedness between renewable energy stocks and crude oil prices, Energy Econ. 76 (2018) 1–20.
[151] Z.Y.I. Abba, N. Balta-Ozkan, P. Hart, A holistic risk management framework for renewable energy investments, Renew. Sustain. Energy Rev. 160 (2022) 112305.
[152] F. Horky, M. Mutascu, J. Fidrmuc, Oil and renewable energy returns during pandemic, Environ. Sci. Pollut. Control Ser. 30 (10) (2023) 25836–25850.
[153] D. Das, D. Maitra, A. Dutta, S. Basu, Financial stress and crude oil implied volatility: new evidence from continuous wavelet transformation framework, Energy Econ. 115 (2022) 106388.
[154] H. Alqaralleh, A. Al-Saraireh, A. Canepa, Energy market risk management under uncertainty: a Var based on wavelet approach, Int. J. Energy Econ. Pol. 11 (5) (2021) 130–137.
[155] H. Han, O. Linton, T. Oka, Y.-J. Whang, The cross-quantilogram: measuring quantile dependence and testing directional predictability between time series, J. Econom. 193 (1) (2016) 251–270.
[156] H. Han, O. Linton, T. Oka, Y.J. Whang, The cross-quantilogram: measuring quantile dependence and testing directional predictability between time series, J. Econom. 193 (1) (2016) 251–270, https://doi.org/10.1016/j.jeconom.2016.03.001.
[157] A.K. Tiwari, E.J.A. Abakah, X. Shao, T.-L. Le, M.N. Gyamfi, Financial technology stocks, green financial assets, and energy markets: a quantile causality and dependence analysis, Energy Econ. 118 (2023), https://doi.org/10.1016/j.eneco.2022.106498, 106498.