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Article

Economic policy uncertainty, energy consumption and environmental sustainability targets

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Abstract: Energy systems face serious difficulties due to economic policy uncertainty, which affects consumption trends and makes the shift to sustainability more difficult. While adjusting for economic growth and carbon emissions, this study examines the dynamic relationship between economic policy uncertainty and energy consumption (including renewable and nonrenewable) in China from 1985Q1 to 2023Q4. The research reveals the frequency-specific and time-varying relationships between these variables by employing sophisticated techniques such as Wavelet Cross-Quantile Correlation (WCQC) and Partial WCQC (PWCQC). Economic policy uncertainty and energy consumption do not significantly correlate in the short term; however, over the long term, economic policy uncertainty positively correlates with renewable energy consumption at medium-to-upper quantiles, indicating that it may play a role in encouraging investments in sustainable energy. On the other hand, EPU has a negative correlation with nonrenewable energy usage at lower quantiles, indicating a slow move away from fossil fuels. These results are confirmed by robustness testing with Spearman-based WCQC techniques. The study ends with policy recommendations to maximize economic policy uncertainty's long-term impacts on renewable energy, reduce dependency on fossil fuels, and attain environmental and energy sustainability in China.

Keywords: environment; energy usage; sustainability; Wavelet Cross-Quantile Correlation China

1. Introduction

This current study replicates the study of Nakhli et al. (2021)[1]. The relationship between economic policy uncertainty, renewable energy, nonrenewable energy, and carbon emission in China is based on specific reasons. Economic policy uncertainty is measured by a risk in which governing structures and their policies are indefinite for the immediate future. This occurrence may lead industries and persons to postpone spending and investment opportunities due to improbability in the market (Akadiri et al., 2020; Al-Thaqeb, 2019). First, it has significant impacts on the real economy; thus, examining the interactions and interconnectedness of such a crucial index with other macroeconomic and environmental variables, especially for an economy like China, can always be emphasized. China is an interesting economy to study because it is one of the world's largest economies; it is also one major player in international dealings (Huang and Luk, 2020).

Second, as one of the emerging nations, China has proved itself worthy of executing major economic policy reforms, potentially prone to policy (uncertainty) shocks. These shocks, in one way or another, impact or influence any economy's macroeconomic and environmental objectives, precisely that of China. According to the World Bank, this paper is centred on China since this nation overtook the United States as the world's leading economy with a US $14.4 trillion GDP in 2019. China is the biggest CO_2 emitter, contributing to roughly 27% of world GHG emissions (World Bank, 2021). This pattern has gradually risen over the years. China now produces 9.9 billion metric tons of CO_2 emissions. Climate policy uncertainty may have significant repercussions on the frequency of China's macroeconomic business cycles since China is now adopting various economic policy measures connected to policy uncertainty shocks. In addition, the means of producing electricity have contributed immensely to air quality (pollution) in China. However, the huge coal-powered factories, which are key contributors to China's economic development, have progressively aided air quality problems in China.

Using the Bootstrap Rolling technique, Nakhli et al. (2021) examine the link between CO_2 emissions, renewable and nonrenewable power consumption, and economic policy uncertainty (EPU) in the United States from 1985M1 to 2020M12. Its results demonstrate a bidirectional association between CO_2 emissions and EPU and a unidirectional causal relationship between energy use and EPU. Nevertheless, statistically unstable factors are also noted in the study, highlighting temporal variability. In line with Sustainable Development Goals (SDGs) 7, 10, and 13, it suggests incorporating sustainable production, energy security, and climate action into economic strategies while considering environmental rules' uncertainty.

As the world's largest energy user and a leader in the development of renewable energy, China was selected to validate the Nakhli et al. (2021) study because it presents a strong argument for analyzing the relationship between energy transitions and economic policy uncertainty (Lin and Xie, 2023a, 2023b, 2024). Due to its long-term pledges to become carbon neutral by 2060, China's energy landscape is different from other countries in that it is rapidly transitioning from a fossil fuel-dominated system to an ambitious renewable energy agenda. Furthermore, compared to other contexts like the US, China's distinctive economic structure—including a centralized regulatory framework and a high sensitivity to domestic and international policy uncertainties—offers a unique setting for evaluating how EPU affects energy consumption patterns. Because of its global importance, aggressive energy goals, and distinct governance, China is a perfect place to evaluate the validity and applicability of results from related studies conducted in other areas.

Besides, the world economy has experienced rapid institutional and structural changes over the years as a result of climate change, energy mix issues, globalization, and changes in economic regulations and policies, among others. Due to its consumption and production purposes, issues related to the environment, patterns and forms of energy sources have gained growing attention among researchers and policymakers, including governments, interested private individuals and firms. Energy consumption as a result of economic activities, either from renewable sources or nonrenewable energy sources, has an essential role in climate changes that have various adverse (carbon emissions) and direct environmental consequences. An economy like China has experienced landslide economic expansion and development over time. However, this nation has also been backlashed as a contributor to world greenhouse gas emissions due to its involvement in massive nonrenewable energy consumption (Chen et al., 2019; Guo et al., 2021). To achieve the Kyoto Protocol Targets alongside sustainable development goals, China is redesigning its economic and environmental policies and structures to attain the set and sustainable environment goals. The nation is also committed to fulfilling the COP29 environmental targets by ending the erection of ceaseless coal power plants, with a phase-out of steady coal power by 2040 or 2050, based on the developmental level of the nation, alongside a speedy rollout of sustainable, efficient and clean energy sources.

The peak in nonrenewable energy consumption has led the economy of China towards severe environmental issues and a surge in carbon emissions and ecological footprint (Ahmed et al., 2020; Wang et al., 2018; Xiong and Li, 2019). The release of greenhouse gas emissions in the atmosphere has led to the destruction of the ozone layer, resulting in global warming and, hence, climate change issues. As stated earlier, China has experienced various policy swings associated with current global climate changes due to the rising presence of CO_2 emissions, alongside economic policy uncertainty that has, in one way or another, influenced the nation's energy mix. The significance of economic policy uncertainty is understudied in literature. On the one hand, heightened economic policy uncertainty directly or indirectly impacts environmental degradation levels via higher nonrenewable energy consumption. On the other hand, it might impact business, manufacturing and industry decision-making.

Increased environmental degradation due to rising CO_2 emissions is associated with household, business, manufacturing, and industry decisions related to the consumption and production of nonrenewable and fossil fuels. An economy prone to weak environmental policies and poor renewable and nonrenewable energy policies coupled with inadequate energy saving and energy-efficient frameworks would be vulnerable to the adverse effects of heightened economic policy uncertainties (Adebayo et al., 2021; Saint Akadiri et al., 2020; Usman et al., 2020; Wang et al., 2022a, 2022b). Lastly, China is the largest in electricity generation from renewable energy sources, followed by the US. By the end of 2019, China had an aggregate capacity of 790 GW of renewable power from solar, hydroelectric and wind power. The nation's hydropower capacity peaked at 356 GW the same year. As of 2020, the installed capacity of the nation, in terms of solar power, peaked at 252 GW and wind power capacity at 282 GW, respectively (Akadiri et al., 2020; Etokakpan et al., 2021). China aims to reach carbon neutrality earlier than 2060 and has the highest emissions earlier than 2030. In 2021, its aggregate renewable energy sources volume surpassed 1000 GW, as the National Energy Administration reported. This accounts for about 43.5% of the aggregate power generation aptitude, about 10.2% greater than in 2015. China is working towards reducing CO_2 emissions per capita by over 65% from the 2005 level. China also plans to increase nonrenewable energy sources' contribution to about 25%, bringing the aggregate mounted aptitude of solar and wind electricity larger than 1200 GW (Wikipedia, 2024).

This current study examines the nexus between economic policy uncertainty and energy consumption (renewable and nonrenewable) in a disaggregated form in the case of China, using a time series quarterly dataset over the periods 1985Q1–2023Q4. This study is motivated by the fact that China is engaged in complex economic activities (Adebayo et al., 2021). Hence, economic policy uncertainty stimulates supply, hurts production activities, and influences investment and business decisions. This study examines the nexus between economic policy uncertainty and energy consumption while controlling economic growth and carbon emissions. This study resonates with existing literature by examining how economic policy uncertainty influences energy consumption (renewable and nonrenewable), economic growth and carbon emissions. Economic policy uncertainty is related to dated shocks associated with fiscal, monetary, trade, and other crucial economic phenomena, such as the China-US trade war and global economic/financial crisis.

This study contributes methodologically and empirically to literature. Methodologically, this study uses sophisticated techniques, such as the new Wavelet Cross-Quantile Correlation (WCQC) and Partial WCQC (PWCQC) approaches, to capture the quantile-based, frequency-specific, and dynamic interactions between these variables during the 1985Q1–20234 data period, as existing studies, rather focus interactions between economic policy uncertainty and other macroeconomic or microeconomic variables. This includes stock returns, the global market, Chinese commodity markets, real housing returns in China, Chinese financial conditions COVID-19 lockdown and firm-level volatility earnings management in China to mention the least (Aye, 2018; Cui et al., 2021; Li et al., 2016; Li and Zhong, 2020; Yang and Yang, 2021; Zhang et al., 2019; Zhu et al., 2021). For this study, the Wavelet Cross-Quantile Correlation (WCQC) and Partial WCQC (PWCQC) approaches are better because they capture the dynamic, frequency-specific, and quantile-based relationships between energy consumption and economic policy uncertainty, offering a more in-depth understanding of conditional and time-varying effects across various scenarios.

Empirically, this study argues that EPU and energy consumption for renewable and nonrenewable sources do not significantly correlate in the near term, according to the data, indicating that short-term changes in policy uncertainty do not have an immediate effect. Long-term uncertainty may encourage investments in renewable energy as a reliable and sustainable substitute, as evidenced by the positive association between EPU and renewable energy use, especially at medium to higher quantiles. In contrast, China's progressive move from fossil fuels in response to uncertainties, environmental constraints, and policy interventions shows the negative long-term connection between EPU and nonrenewable energy use, particularly at lower and medium quantiles. The validity of the results is confirmed by robustness checks utilizing Spearman-based WCQC and PWCQC methods, which show consistency across various correlation estimation methodologies.

These results highlight the importance of considering both distributional and temporal dynamics when assessing how economic policy uncertainty and energy usage interact.

Conclusively, by emphasizing the complex consequences of policy uncertainty in China's particular context—where long-term government planning, aggressive renewable energy targets, and environmental commitments play crucial roles—this study adds to the body of literature on energy transition and environmental sustainability. The findings imply that although EPU presents difficulties, it might eventually catalyze the switch to green energy. The rest of the paper is scheduled as follows. Section 2 is about data and methodology. Section 3 presents empirical results and discusses them accordingly. Section 4 gives concluding remarks and policy suggestions.

2. Materials and method

2.1. Materials

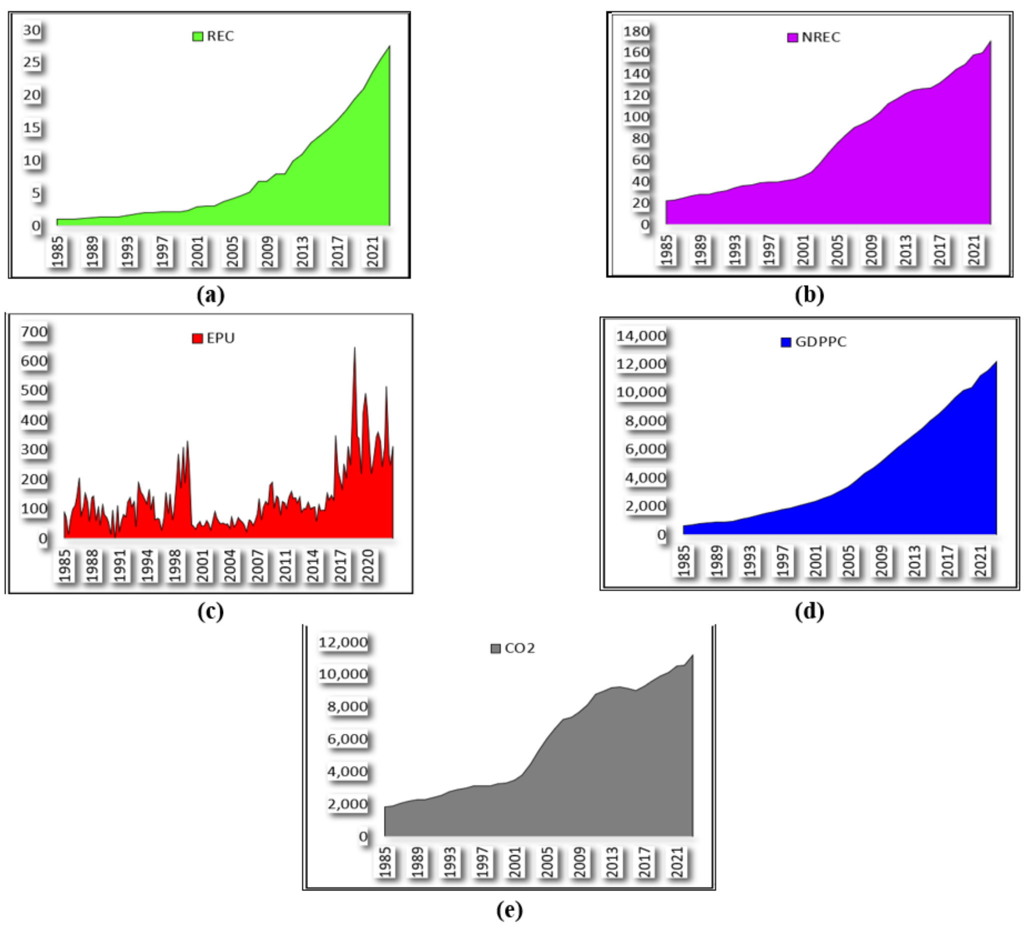


Figure 1. Time trend plots of the quarterly EPU and annual REC, NREC, GDPPC, and CO_2.

In this research, we assess the nexus among economic policy uncertainty, energy sources (renewable and nonrenewable), CO_2 emissions, and economic growth in China (the biggest emitter globally). The dataset used in this empirical analysis spans from

1985Q1 to 2023Q4[2]. The dataset for economic policy uncertainty (EPU) was gathered from Economic Policy Uncertainty[3]), a database based on mainland newspapers. We extract economic growth data from the World Bank database (measured as GDP per capita constant), energy[4] (renewable and nonrenewable) were gathered from the British Petroleum database (measured as exajoules), and CO_2 emissions were also obtained from the British Petroleum database (metric tons per capita). To address non-stationarity, quarterly series are converted to log change series as $\ln(V_{it+1}/V_{it})$, where ln is logarithm, V_{it+1} is the value of the *i*-th variable at time $t + 1$, and V_{it} is the value of the *i*-th variable at time *t*. **Figure 1** presents the log and log difference trend of variables under investigation.

Particularly when considering the relationship between EPU and energy consumption (both renewable and nonrenewable) in China, **Table 1** offers important insights into the dynamics of the variables being studied. EPU is very variable, as seen by its large range (−4.575 to 4.730) and high standard deviation (0.756), which may be related to shifts in policy or developments in the world economy. This fits nicely with your chosen Wavelet Cross-Quantile Correlation approach, which may capture dynamic correlations across different quantiles and temporal scales. Extreme downward events are more common, even if uncertainty normally moves upward, according to the EPU's positive mean (0.008) and negative median (−0.020). Such dynamic behavior calls for a more thorough examination of the effects of varying degrees of uncertainty on energy usage patterns.

Table 1. Descriptive statistics.

	REC	**NREC**	**EPU**	**GDPPC**	**CO_2**
Mean	0.022	0.013	0.008	0.019	0.012
Median	0.021	0.012	−0.020	0.018	0.010
Max	0.142	0.046	4.730	0.041	0.050
Min	−0.068	−0.010	−4.575	−0.010	−0.014
Std. Dev.	0.025	0.010	0.756	0.007	0.012
Skewness	0.701	0.868	0.107	−0.465	0.843
Kurtosis	9.027	4.445	19.925	5.232	4.263
Jarque-Bera	247.257***	32.951***	1850.215***	37.760***	28.676***
Prob.	0.000	0.000	0.000	0.000	0.000

Note: *** mean Prob. < 0.01.

China is focusing more on renewable energy, as evidenced by the REC variable's slightly higher average (0.022) than the NREC (0.013). However, the high Kurtosis of REC (9.027) indicates strong spikes that are probably caused by interventions or changes in policy, which wavelet approaches can successfully investigate. NREC, on the other hand, shows greater stability (a lower standard deviation of 0.010), indicating a steady reliance on alternative energy sources. While GDPPC has low variability but a minor negative skew (−0.465), suggesting lower growth rates are more prevalent, CO_2 remains steady with moderate Kurtosis (4.263), making it a solid control variable. When taken as a whole, these statistics demonstrate the intricate, nonlinear interactions between the variables, supporting the application of sophisticated techniques such as Wavelet Cross-Quantile Correlation to identify immediate and long-term interdependencies. Adjusting for emissions and economic growth assists in separating the effects of EPU on energy consumption, offering crucial information for policy changes in China's energy industry.

According to Adebayo and Özkan (2024), the Quantile ADF (QADF) graphical depiction in **Figure 2** offers a reliable framework for evaluating the stationarity of series over several quantiles, identifying changes that conventional unit root tests could miss. According to the QADF test results, the series being studied are integrated of order one (I (1)) since they are stationary at the initial difference during the sample period. This discovery suggests that the first-differenced series stabilizes, making it appropriate for sophisticated time-series analysis like Wavelet Cross-Quantile Correlation, even when the original data shows non-stationarity—possibly due to underlying trends, structural fractures or persistence. The test validates the suitability of first differencing in capturing the dynamic links between economic policy uncertainty, energy consumption, economic growth, and carbon emissions by guaranteeing stationarity. This also supports the trustworthiness of the following econometric analyses.

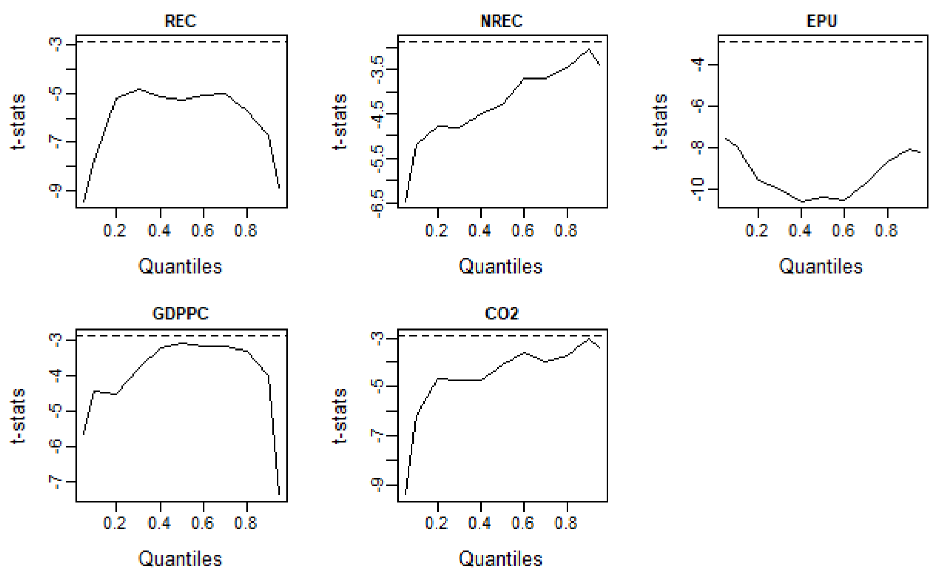


Figure 2. QADF results.

Note: -- represents a 5% threshold.

The BDS test (Broock et al., 1996) analyzes whether nonlinearity exists in time series and offers important insights into intricate dynamics that linear models could miss. The results indicate significant nonlinear dependencies, which show an increasing trend in the BDS graphical plots for the whole series (**Figure 3**). This result is consistent with the study's goal of examining the complex links between China's energy consumption (renewable and nonrenewable) and economic policy uncertainty (EPU) while adjusting for economic growth and carbon emissions.

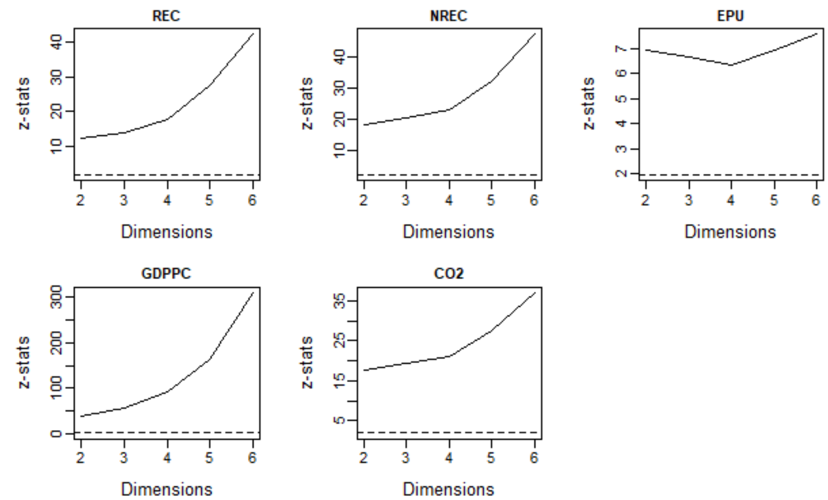


Figure 3. BDS results.

Note: -- represents a 5% threshold.

The nonlinearity discovered highlights the suitability of sophisticated techniques, such as Wavelet Cross-Quantile Correlation, which can handle this complexity by capturing dynamic correlations across quantiles and temporal scales. The increasing tendency in the BDS plots may reflect changing trends in energy consumption and policy uncertainty, such as structural changes in China's energy transition or governmental reactions to outside economic shocks. Developing focused policy recommendations to control uncertainty and maximize energy use to achieve sustainable growth requires understanding these nonlinear dynamics.

2.2. Method

In order to investigate the frequency-specific cross-quantile relationship between the time series, this study presents the Wavelet Cross-Quantile Correlation (WCQC) as a novel empirical analysis technique (Chishti et al., 2025). The MODWT architecture of Percival and Walden (2000) is used by existing methods, including wavelet correlation, quantile correlation, and wavelet quantile correlation (Kumar and Padakandla, 2022; Li et al., 2015; Whitcher et al., 2000). However, they only concentrate on the quantiles of a single series. Similarly, the quantiles of both series are analyzed by the cross-quantilogram; however, the MODWT is not integrated. Nevertheless, these methods have yet to simultaneously investigate the links between the quantiles of both series and wavelet analysis (Han et al., 2016). The WCQC method fills this gap by utilizing wavelet analysis with quantile-based insights from both time series. This allows for a thorough investigation of frequency-specific cross-quantile dynamics. This invention makes a more thorough examination of the relationships between variables across various periods and quantiles possible.

Multiple steps are involved in applying the WCQC method: First, both series are standardized using the methodology described by Baruník and Kley (2019). The Maximum Overlap Discrete Wavelet Transform (MODWT), which spans from scale 1 to the maximum decomposition depth (ϕ)[5], is then used to decompose the standardized series. Third, the quantile estimation method put forward by Li (2022) estimates the conditional quantile series of the decomposed series. Lastly, each quantile pair's correlation coefficients are estimated via the WCQC. The following is an estimate of the WCQC coefficients for the variables in Equation (1):

$$wcqc(A,B) = C(\emptyset A_t^\tau, \emptyset B_t^\tau) \quad (1)$$

where C indicates correlation and $\emptyset A_t^\tau$ and $\emptyset B_t^\tau$ stand for the τ-th quantile of the $\emptyset$-th decomposition series of A_t and B_t, respectively. Because it considers both the frequency and quantile-dependent connection between two variables, the WCQC is a nonlinear technique. Since the Kendall and Spearman correlation methods are more resilient to nonlinear interactions and do not rely on linearity and normality as the Pearson correlation approach does, they are appropriate for the WCQC. The following is an estimate of the WCQC coefficients using the Kendall and Spearman correlation methods specified in Equations (2) and (3):

$$kwcqc(A,B) = \frac{2(CP - DCP}{n(n-1)} = \frac{2}{n(n-1)} \sum_{t<i} S(\emptyset A_t^\tau, \emptyset A_t^\tau) S(\emptyset B_t^\tau, \emptyset B_t^\tau) \quad (2)$$

$$swcqc(A,B) = 1 - \frac{6 \sum (R\emptyset A_t^\tau, R\emptyset B_t^\tau)^2}{n(n^2-1)} \quad (3)$$

where the Kendall and Spearman WCQC correlations are denoted by $kwcqc$ and $swcqc$, respectively. This work's new WCQC and Partial WCQC approaches address the drawbacks of earlier relevant approaches. However, they have certain drawbacks, like failing to consider time-varying and lag-lead correlations.

We additionally present Partial Wavelet Cross-Quantile Correlation (PWCQC) to investigate how altering the third variable affects the frequency cross-quantile relationship between two variables. The following is an estimate of the PWCQC:

$$pwcqc(A,B) = wcqc(A,B) - E(C) - E(I) \quad (4)$$

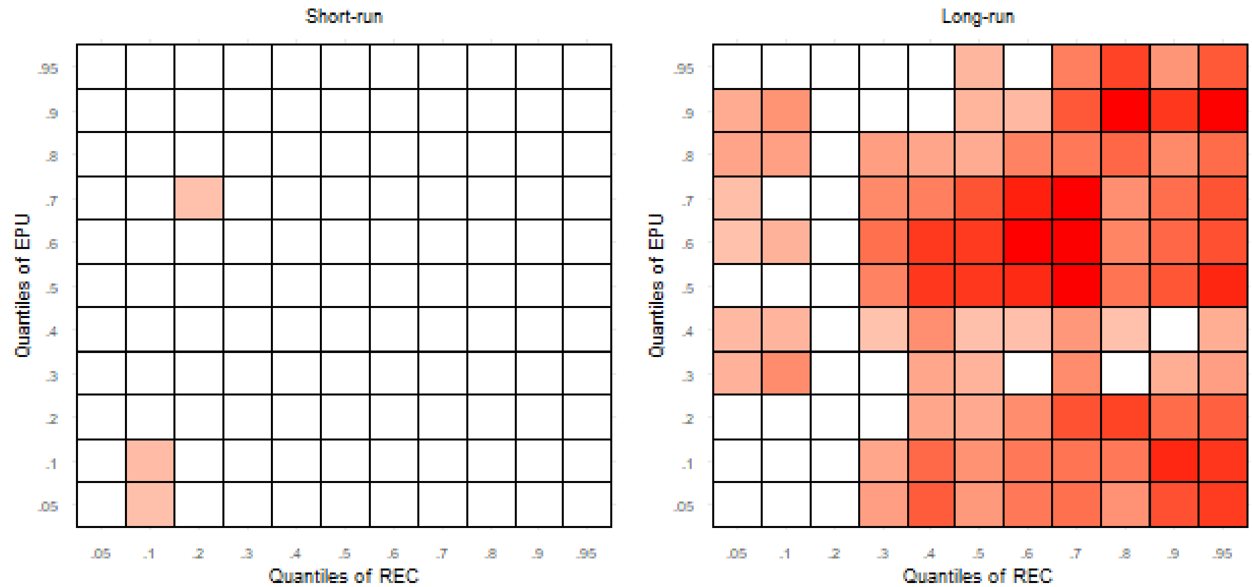
where *E(C)* and *E(I)* imply the effect of the third variable and its interaction on the frequency cross-quantile correlation between two variables, respectively. *E(C)* and *E(I)* can be calculated below in Equations (5) and (6):

$$E(C) = wcqc(A,B) - \frac{C(\emptyset A_t^\tau, \emptyset B_t^\tau) - C(\emptyset A_t^\tau, \emptyset C_t^\tau) C(\emptyset B_t^\tau, \emptyset C_t^\tau)}{\sqrt{1 - C^2(\emptyset A_t^\tau, \emptyset C_t^\tau) 1 - C^2(\emptyset B_t^\tau, \emptyset C_t^\tau)}} \quad (5)$$

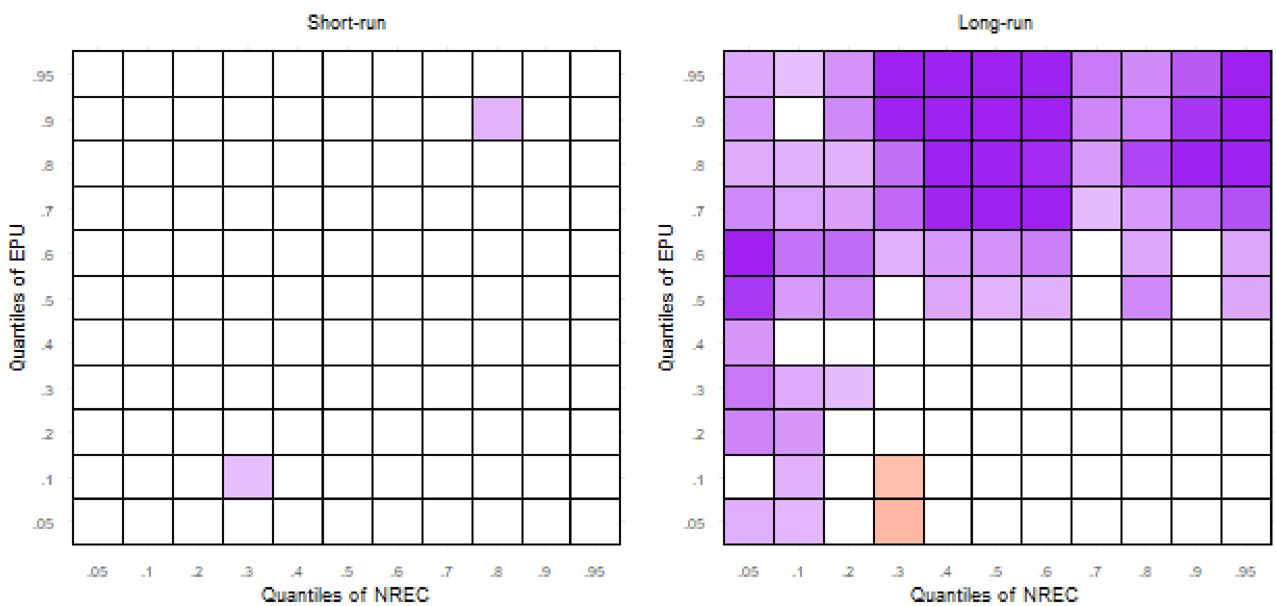
$$E(I) = wcqc(A,B) - \frac{C(\emptyset A_t^\tau, \emptyset B_t^\tau) - C(\emptyset A_t^\tau, \emptyset I_t^\tau) C(\emptyset B_t^\tau, \emptyset I_t^\tau)}{\sqrt{1 - C^2(\emptyset A_t^\tau, \emptyset I_t^\tau) 1 - C^2(\emptyset B_t^\tau, \emptyset I_t^\tau)}} \quad (6)$$

The Kendall and Spearman correlation techniques, like WCQC, can also be used to estimate the PWCQC coefficients.

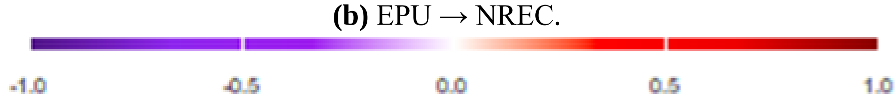
3. Empirical outcomes and discussion of findings



(a) EPU → REC.



(b) EPU → NREC.



(c)

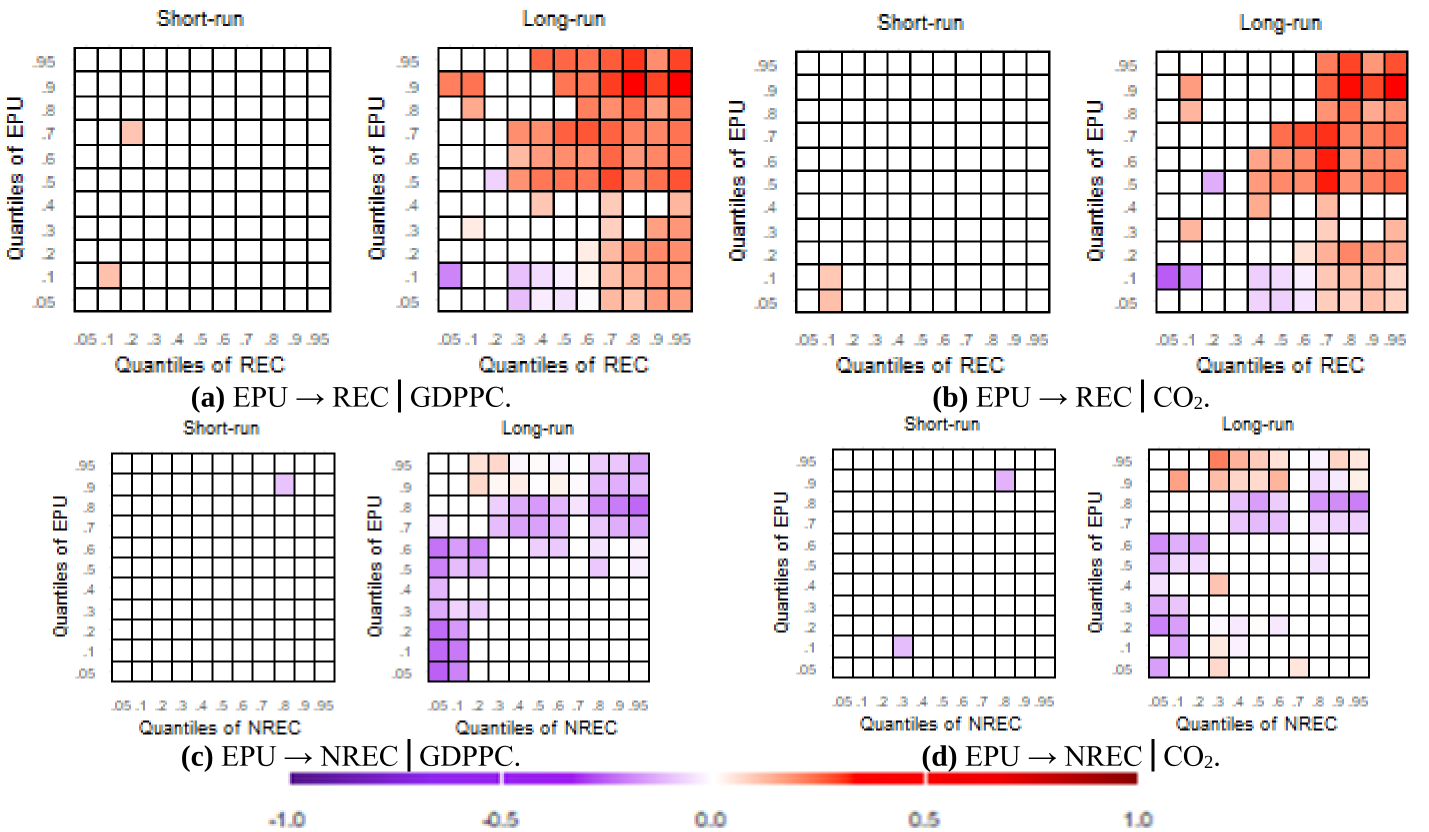
Figure 4. Kendall-based WCQC estimates.

Figure 4 reports the results based on the Kendall WCQC method. It is crucial to remember that a positive QC between the independent and dependent series indicates that the independent series is causing environmental quality to improve; if not, it indicates that environmental quality is declining. We need discernible association in the short run (SR) when considering the renewable energy situation. Nonetheless, EPU positively correlates with renewable energy in the long run (LR) across all quantiles, suggesting that renewable energy sources help China meet its environmental sustainability goals (Akadiri et al., 2020).

According to this research, increased EPU may eventually encourage investment and policy changes in favour of renewable energy, even while short-term variations in policy uncertainty might not immediately influence changes in the use of renewable energy (Akadiri et al., 2022; Hilili et al., 2024; Tule et al., 2024). This may be explained in the case of China by the government's deliberate emphasis on the development of renewable energy, particularly in light of its larger environmental sustainability goals. Long-term planning and initiatives, like China's pledge to become carbon neutral by 2060, may create an atmosphere where economic policy uncertainty eventually encourages a transition toward renewable energy despite the possibility of short-term policy instability or uncertainty. Subsidies, tax breaks, and infrastructure expenditures are some policies that could encourage greater use of renewable energy technologies and support environmental sustainability objectives. This finding emphasizes the unique characteristics of China's economic and policy environment, where long-term planning and government intervention frequently exceed the short-term effects of policy uncertainty.

Nonetheless, the empirical finding that EPU and NREC have a negative long-term association but no substantial short-term link with NREC consumption provides important new information about China's energy dynamics (Aslan et al., 2024; Nakhli et al., 2021). According to this research, increased policy uncertainty may help reduce the use of NREC sources, which is consistent with the general objective of enhancing environmental quality. Regarding China, this unfavorable correlation may be explained by the nation's increasing attempts to move away from fossil fuels and toward more environmentally friendly energy sources. NREC use may eventually fall due to China's growing commitment to environmental sustainability, demonstrated by its aggressive carbon reduction targets and investments in REC technologies. Even while EPU will not have an immediate impact, it might cause long-term changes in the energy market as the government works to reduce the risks associated with climate change and conform to international environmental standards. The negative long-term association between EPU and NREC may react to growing regulatory pressure and international environmental expectations, which is especially pertinent considering China's emphasis on pollution reduction and environmental quality improvement. China's strong government-driven push for sustainability, which may mitigate the negative effects of policy uncertainty in the near term but eventually lead to a move away from NREC in the long term, makes the sample country unique.

Using the new PWCQC approach, the result shown in **Figure 5** shows the conditional link between EPU and energy consumption (both renewable and nonrenewable) while adjusting for CO_2 emissions and economic growth throughout the sample period. The result shown in **Figure 5** investigates the partial impacts of CO_2 emissions and economic growth on the relationship between EPU and REC over the sample period. After adjusting for the effects of CO_2 emissions and economic growth, the results show no significant link between EPU and REC in the SR. This implies that policy uncertainty does not, in the short term, directly or immediately affect the use of renewable energy. The effects of policy uncertainty on adopting renewable energy may be obscured by short-term economic conditions and emissions levels caused by the continued reliance on fossil fuels.



(e)

Figure 5. Kendall-based PWCQC estimates.

However, after adjusting for CO_2 emissions and economic growth, the results indicate a strong positive association between EPU and REC in the LR at medium to higher quantiles. This suggests that greater economic policy uncertainty might eventually promote the use of renewable energy sources (Akadiri et al., 2022). Long-term policy uncertainty may encourage more investment in renewable energy as part of a plan to diversify energy sources and improve energy security, especially when fossil fuel markets are unstable, or sustainability targets must be met. Despite the short-term volatility brought on by the uncertainty surrounding economic policy, this could be the consequence of long-term changes in policy or heightened market confidence in renewables.

The LR's medium to upper quantiles showed a positive correlation, implying that renewable energy is a more reliable and sustainable option in times of increased uncertainty. This could result in increased investments and expansion in the renewable energy industry. This discovery could be understood in the context of China as a reaction to the government's environmental goals and long-term commitments to renewable energy. The long-term trend mirrors China's larger strategic shift towards cleaner energy sources, where policy uncertainty may speed this shift as part of a broader resilience plan, even as short-term concerns impede urgent transitions. The importance of CO_2 emissions and economic growth as controls highlights even more how complicated the long-term dynamics of the energy transition are and how they are influenced by structural factors other than policy uncertainty.

In addition, we consider how CO_2 emissions and economic growth partially affect the link between EPU and NREC in **Figure 5**. After adjusting for the SR's economic development and CO_2 emissions, the results indicate no discernible relationship between the EPU and NREC. After accounting for the immediate effects of economic growth (which frequently leads to higher energy demand) and CO_2 emissions, there is no discernible relationship between EPU and NREC, indicating that short-term policy uncertainty does not directly impact NREC (Aslan et al., 2024; Nakhli et al., 2021). This may suggest that the continuous reliance on NREC and the immediate pressures of economic growth outweigh the short-term effects of economic policy uncertainty.

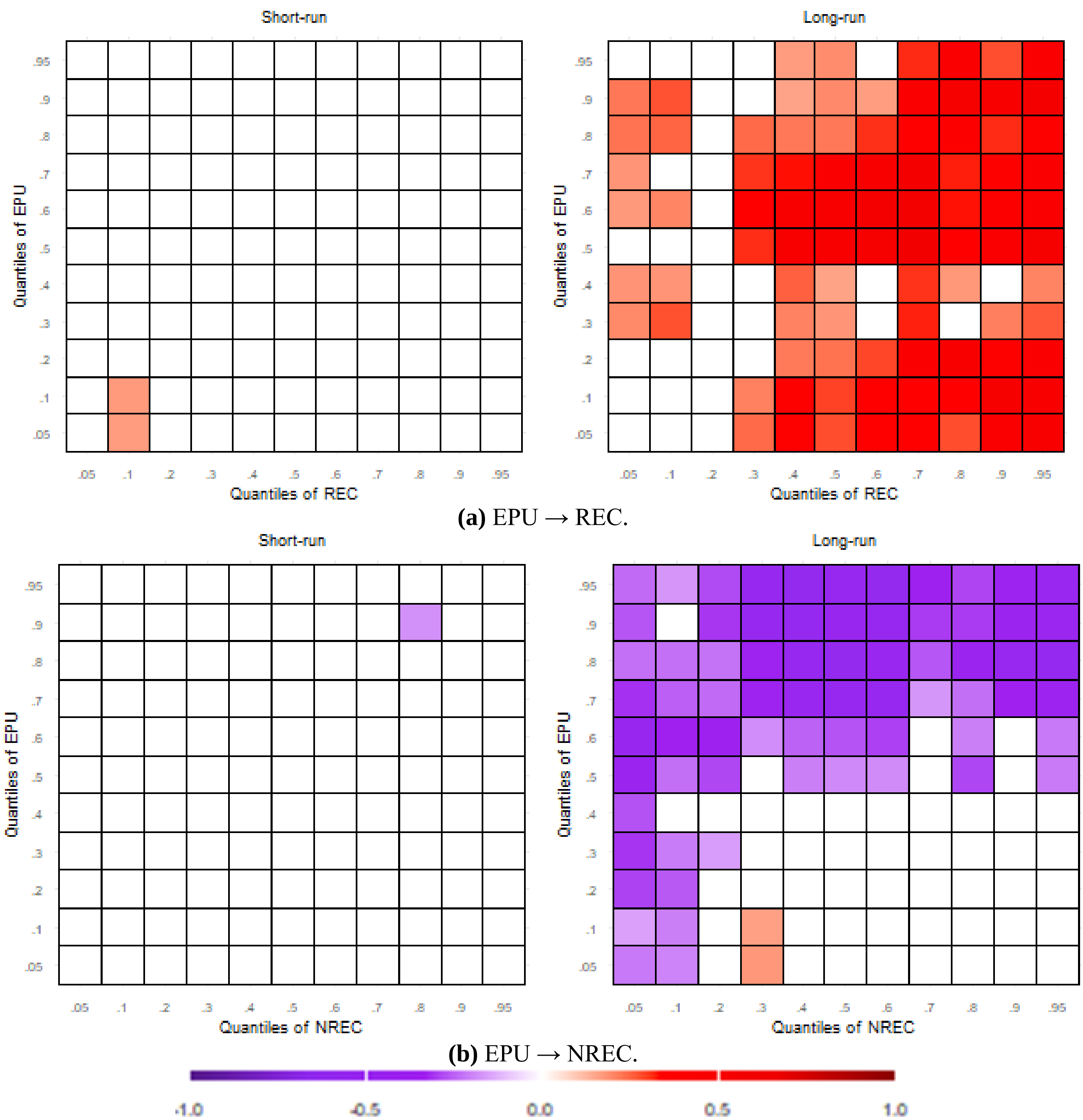
However, after adjusting for CO_2 emissions and economic growth, the results show a substantial negative connection between EPU and NREC in the LR, especially in the left and right tails of the distribution. The economic growth distribution's left tail (0.01–0.50) and right tail (0.70–0.95), as well as the CO_2 emissions distribution's left tail (0.01–0.020) and medium quantiles (0.30–0.80), both exhibit this negative association. These findings imply that increased economic policy uncertainty may eventually result in less dependence on NREC, particularly in situations with moderate to high CO_2 emissions and very low or fast economic growth. This might be a sign of a long-term change in energy policy, as economic instability forces a reassessment of energy dependence and encourages the adoption of more sustainable energy systems, possibly in response to energy security plans or environmental concerns.

However, in the upper quantiles (0.90–0.95) of CO_2 emissions, there is a positive correlation between EPU and NREC, suggesting that economic uncertainty may increase reliance on NREC sources during high emissions periods. This might result from the perception that secured, and easily accessible energy sources are necessary in uncertain policy times, particularly when emissions are high. The need to control energy demand may take precedence over environmental concerns.

This intricate link illustrates how energy use patterns, environmental concerns, and economic uncertainties interact dynamically. These findings imply that, although economic policy uncertainty may eventually encourage cleaner energy transitions in the context of China, there are times when uncertainty may make dependence on NREC sources worse, especially during times of high emissions. This aligns with China's problem of balancing environmental sustainability, energy security, and economic growth. Policy uncertainty may have two effects depending on the larger economic and environmental context.

Robustness check

Figures 6 and **7** show the results of the initial robustness assessment using the Spearman WCQC and Spearman PWCQC methods, respectively. The results given for Kendall-based WCQC estimates and Kendall-based PWCQC estimates are consistent with the Spearman WCQC-based and Spearman PWCQC-based results, supporting the primary conclusions.



(a) EPU → REC.

(b) EPU → NREC.

(c)

Figure 6. Spearman-based WCQC estimates.

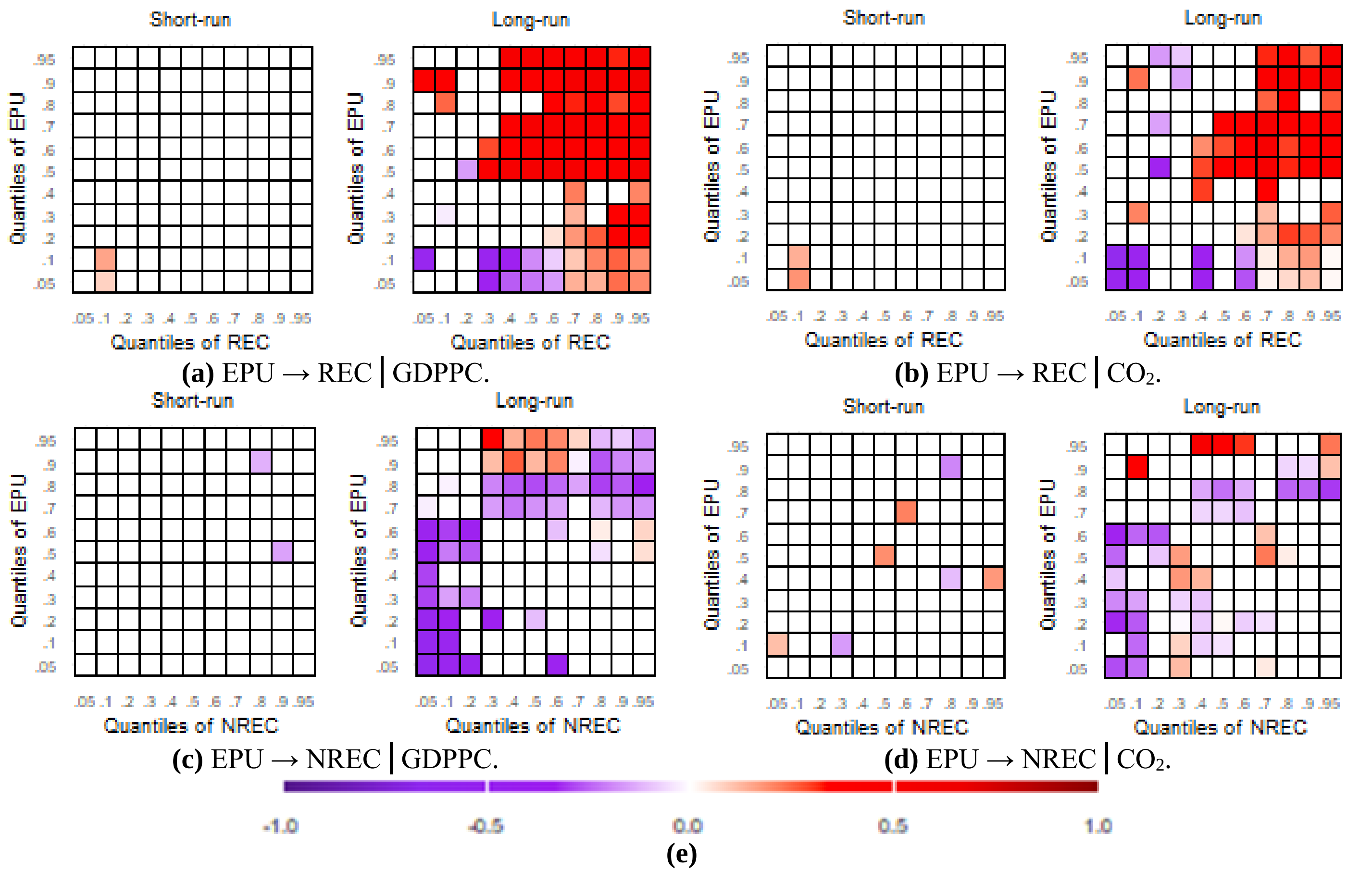


Figure 7. Spearman-based PWCQC estimates.

The validity of the study's primary findings is further supported by the results of the robustness check conducted using the Spearman Wavelet Cross-Quantile Correlation (WCQC) method (**Figure 6**) and the Spearman Partial WCQC (PWCQC) method (**Figure 7**). The relationship between EPU and energy consumption (both renewable and nonrenewable) across various time scales and quantiles is evaluated by these methods, such as the Kendall-based WCQC and PWCQC estimates. Spearman's rank correlation provides an alternative measure of association based on the ranking of observations rather than their actual values.

The robustness of the study's main conclusions is demonstrated by the consistency between the results obtained using the Spearman-based methods and those provided using the Kendall-based approaches. The main trends in the interactions between EPU and energy consumption (both renewable and nonrenewable) are supported by both methodologies, especially the absence of short-term significance and the appearance of long-term correlations (both positive and negative) across quantiles. The Spearman framework, for example, confirms the strong long-term positive correlation between EPU and REC and the complex negative and positive correlations between EPU and NREC.

The results demonstrate the resilience and dependability of the WCQC methodology in capturing the intricate, time-varying interactions between the variables by producing comparable results under two different correlation estimation techniques. The validity of these findings in separating the direct impacts of EPU on energy consumption while taking other influencing factors into account is further supported by the application of the partial Spearman WCQC (PWCQC) to account for economic growth and CO_2 emissions. In addition to confirming the study's methodological soundness, this robustness assessment boosts trust in the findings' theoretical and policy implications for energy transition plans and environmental management in the Chinese setting.

4. Conclusion and policy recommendations

4.1. Conclusion

After adjusting for economic growth and carbon emissions, this study investigates the complex relationship between China's energy consumption—both renewable and nonrenewable—and economic policy uncertainty (EPU). The study uses sophisticated techniques, such as the new Wavelet Cross-Quantile Correlation (WCQC) and Partial WCQC (PWCQC) approaches, to capture the quantile-based, frequency-specific, and dynamic interactions between these variables during the 1985Q1–20234 data period. The results offer a number of important new perspectives on how policy uncertainty influences China's energy consumption trends.

According to the data, EPU and energy consumption for both renewable and nonrenewable sources do not significantly correlate in the near term, indicating that short-term changes in policy uncertainty do not have an immediate effect. Long-term uncertainty may encourage investments in renewable energy as a reliable and sustainable substitute, as evidenced by the positive association between EPU and renewable energy use, especially at medium to higher quantiles. In contrast, China's progressive move from fossil fuels in response to uncertainties, environmental constraints, and policy interventions shows the negative long-term connection between EPU and nonrenewable energy use, particularly at lower and medium quantiles. The validity of the results is confirmed by robustness checks utilizing Spearman-based WCQC and PWCQC methods, which show consistency across various correlation estimation methodologies. These results highlight the importance of considering both distributional and temporal dynamics when assessing how economic policy uncertainty and energy usage interact.

4.2. Policy direction

Several results-driven policy initiatives are suggested to alleviate the effects of economic policy uncertainty on energy consumption and further China's objectives for environmental sustainability and energy efficiency. To promote the expansion of renewable energy, authorities should first concentrate on enhancing policy certainty. According to the study, while EPU encourages sustained investments in renewable energy, these benefits would be amplified by a stable regulatory environment. Precise and uniform frameworks are essential for renewable energy projects. Examples include feed-in tariffs, subsidies, and long-term tax benefits. Furthermore, increasing openness in the creation and application of policies helps allay investor concerns and guarantee continued investments in renewable energy even in times of uncertainty.

Second, renewable energy needs to be promoted as a long-term strategic asset. The results show that renewable energy consumption rises in medium-to-upper quantiles of EPU, indicating that it can be a reliable energy source in unpredictable times. Investments in renewable energy infrastructure, such as wind and solar farms, should be increased in tandem with sophisticated grid technologies to increase integration and dependability. To further establish renewables as a pillar of China's energy future, public-private partnerships should be reinforced to use private sector capital and experience for large-scale renewable energy projects.

With well-defined transition plans, efforts should be made to phase out nonrenewable energy simultaneously. The study highlights the slow reduction in dependency on fossil fuels by demonstrating a negative long-term association between EPU and nonrenewable energy. To help impacted workers, policymakers should develop workforce retraining programs and gradually reduce subsidies for fossil fuel businesses. Stricter enforcement of environmental regulations can hasten the transition, while carbon pricing mechanisms like carbon taxes or emissions trading systems can deter the use of nonrenewable energy.

It is crucial to reduce short-term policy uncertainty by adaptable measures to address the absence of notable short-term effects of EPU. During increased short-term uncertainty, policymakers should consider establishing contingency reserves or adaptable finance methods to assist renewable energy projects. Flexible renewable energy purchase techniques can also safeguard against brief changes in the economy or policy, preventing the advancement of energy transition objectives from being halted. Furthermore, considering the interdependent dynamics of EPU, economic growth, and CO_2 emissions, it is imperative to match environmental objectives with priorities for economic growth. To ensure that economic growth is in line with China's carbon neutrality goals, the national economic strategy should completely incorporate renewable energy development. Prioritizing incentives for clean energy technology research and development can help spur innovation that lowers emissions and promotes economic growth. International cooperation should also be promoted to embrace best practices from around the world and draw in foreign capital for the transition to renewable energy.

Lastly, it is critical to assess and monitor policies' efficacy regularly. The significance of adaptive policymaking is highlighted by the dynamic links that exist between EPU and energy usage. Policymakers should set up reliable monitoring systems to assess the effects of energy policies and make necessary adjustments in light of observed results. Data-driven strategy creation can also benefit from real-time energy consumption estimates and analysis. In order to maintain momentum toward a sustainable energy future, energy transition plans should be updated on a regular basis to guarantee they stay adaptable to changing regulatory environments and economic realities.

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Data availability statement: Data will be provided upon reasonable request.

Ethical approval: Not applicable.

Conflict of interest: The authors declare no conflict of interest.

Notes

1 For brevity, there is no section for literature reviews. Interested readers should see Nakhli et al. (2021) for a detailed literature review on the subject matter.

2 Quarterly values of REC, NREC, GDPPCD, and CO_2 are calculated via a quadratic match sum procedure provided by EViews.

3 https://www.policyuncertainty.com/china_epu.html

4 Renewable energy use (Solar et al., and Wind) and nonrenewable energy (Oil et al.).

5 Notably, as advised by Polanco-Martínez (2023), the maximum depth (scale) of the decomposition (ϕ) is approximated as $\log2(n) - 3$, where n is the total number (i.e., duration) of the sample period.

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