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Riding the Green Wave: How Clean Energy Is Reshaping China's Stock Market

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Abstract
The clean energy industry has recently garnered marked attention, as it does not only mitigate greenhouse gas (GHG) emissions, but it also serves as a novel investment avenue, which may propel the size of the stock market. With this backdrop, this study aims to assess whether clean energy augments the size of the stock markets in China, utilizing the wavelet coherence (WCA) and the Breitung-Candelon spectral causality approaches. The empirical analysis shows that clean energy has significant positive effect on the development of both the Shanghai and the Shenzhen stock markets across different times and frequencies. The spectral causality approach further affirms the lead-lag relationship between clean energy and China's stock market development across different frequencies. Based on these findings, we suggest that the Chinese government should pave the way for clean energy projects, which will bolster both domestic and foreign investment, eventually, boosting China's stock growth. The study offers actionable insights for environmentally conscious and energy investors. It highlights the significance of clean energy in China's stock market for achieving sustainable development in China.

Keywords Clean energy · Stock market growth · Wavelet coherence · Spectral causality · China

Introduction

The depletion of non-renewable energy sources and global warming issues have recently grabbed the worldwide attention of policymakers and practitioners towards opting for renewable energy as an alternative energy source. With the growing need for environmental sustainability and technology development, clean energy sources are considered an indispensable option (Kostis et al., 2023; Musah et al., 2024). Similarly, most of the emerging and developing countries are still struggling

Extended author information available on the last page of the article to switch towards a clean energy framework from an unclean energy setup. The key concern for researchers is to explore factors that lead to sustainable growth, with clean energy sources being a cardinal element (Antonakakis et al., 2017; Kushwaha et al., 2023; Boubacar et al., 2024).

Mitigating global warming and environmental issues are now quintessential to every country as they are deemed to be a severe threat to the sustainability of the world (Ullah et al., 2023). Countries have realized that achieving economic growth via consumption of non-renewable energy is no longer an apt decision and vowed to curtail carbon emissions in the Paris Agreement. Countries are now searching for alternative/clean energy sources to fulfill their energy needs concurrently cope with global warming (Bölük & Mert, 2014). China being the world's second-largest CO_2 emitter has also taken practical steps to tackle the issues espoused by carbon emissions (Yang et al., 2023; Pata et al., 2023). In this respect, China has developed a national plan and has vowed to restructure its industry sector and become energy energy-savvy country. China plans to curb Co_2 emissions by 2030. To sustain the massive growth of its economy, Chinese energy consumption increased manifold in the last decade. However, this enormous growth was achieved at the cost of severe environmental pollution resulting from fossil fuel consumption. The problem of increasing greenhouse gas (GHG) emissions, the increase in volatility of oil prices, and ever-changing geopolitics tempted China to increase its share of clean energy in recent times. Apart from that, increasing the share of renewable energy in an energy mix of a country also reduces the burden on foreign exchange. Being the largest importer of fossil fuels makes China highly vulnerable to the turbulent global political environment thereby disrupting the fuel supplies. Unlike traditional fossil fuels, renewable energy in the form of solar, tidal, and wind energy is widely available thereby decreasing the dependence of the Chinese economy on other countries.

China is increasing its dependence for energy on alternatives to fossil fuels (oil, natural gas, and coal). China now stands as the world's largest exporter, manufacturer, and installer of solar panels, wind turbines, batteries, and electric vehicles. The rapid expansion of the clean energy industry entices investors to pour in additional investment to the sector and concurrently may guide policymakers on whether clean energy changes have favorable impact on stock market growth in China. The theoretical foundation on the relationship between clean energy and the stock market is based on similar grounds as the effect of oil prices on the stock markets. However, it is still an unfamiliar concept whether clean energy affects stock prices in a similar fashion to oil prices? More precisely, this article attempts to explore whether clean energy determines the size of the stock market in China. The current study specifically explores the existence of this relationship since China's share in clean energy has grown tremendously in the overall energy mix in recent times. Against this backdrop, investigating the relationship between clean energy changes and stock market development in the context of China merits attention.

Both emerging and developing economies are pouring in more investment in renewable energy projects. The developing countries global spending on renewable energy witnessed a surge from \$30.5 billion to \$61.6 billion for the period 2008–2018. China, being the second-largest economy in the world, has allocated more investment towards renewable energy projects than any country in the world in

2018. The total investment of China on renewable energy was close to $92.2 billion compared to Europe ($61.2 billion) and the US ($48.5 billion). Countries having well-developed financial markets may provide access to external financing and can easily augment the renewable energy sector. We contend that the financial market in China is not very mature to offer substantial capital for investment in clean energy projects. The renewable energy sector does not only require heavy external financing but also require sophisticated technology. Renewable energy not only is risky but also suffers from the disadvantage of high initial upfront cost (Ma et al., 2019). Given that the energy sector is government-driven, in this respect, the role of the government in supporting clean energy projects may strengthen the clean energy sector, which, in turn, can augment the size of the Chinese financial market. In this regard, renewable energy demands depth in financial markets.

Quite a few studies have investigated the impact of non-renewable energies on financial development, and limited studies have addressed the question that stock market development determines clean energy use (Paramati et al., 2016; Razmi et al., 2020). Unlike the works of Paramati et al. (2016) and Razmi et al. (2020), we posit that clean energy may also determine stock market growth as it creates more investment avenues which, in turn, may increase the size of the stock market. This research work is taking the case of China as it is confronted with environmental issues and the Chinese government has defined goals of moving towards a cleaner economy. Another point of difference between our and Paramati et al. (2016) and Razmi et al. (2020) is that they have used linear models (both panel and time series) to determine the link between stock market growth and clean energy usage. We contend that the relationship between clean energy and stock market growth merits further attention through the lens of time and frequency domains. Hence, this study will augment the literature by exploring the short-, medium, and long-run asymmetric association between clean energy and stock market development in the context of China, utilizing both time and frequency domain approaches. The asymmetric approaches including the wavelet coherence and frequency domain approaches have been widely used to solve various research questions as they are capable of detecting nonlinearities in various domains of economics and finance (Afshan et al., 2018; Ma et al., 2023; Xuefeng et al., 2022; Razzaq et al., 2023; Oshodi & Olasehinde-Williams, 2024).

The results show that clean energy propels the size of China's stock market across different times and frequencies. These outcomes suggest that by facilitating clean energy projects, the Chinese government can further lubricate the wheel of both domestic and foreign investment. This, in turn, will invigorate investment in China's stock market. Underscoring the importance of investment in the clean energy sector, this research work study also offers practical implications for achieving sustainable development goals in China.

The following section outlines the structure of the study. The "Literature Review" section presents a review of the previous research works. The "Data and Econometric Methodology" section reports the data and discusses the employed econometric tools. The "Results and Discussion" section reports the results and discussion. Finally, the "Concluding Remarks" section concludes the study.

Literature Review

The literature on the energy-growth nexus has further expanded and gained increased attention in recent years (see, for instance, Mediavilla et al., 2013; Mandelli et al., 2014; Oyedepo, 2014; Qi et al., 2014; Sanoh et al., 2014). The investigation of clean energy and non-renewable energy sources on economic growth gives comprehensive insights into the execution and implementation of sustainable environmental and renewable energy frameworks for both developing and developed economies (Apergis & Payne, 2010). This has developed the need to address and examine the clean and efficient energy linkages with economic development.

Prior studies, for instance, Ajayi and Ajayi (2013) evaluated the renewable energy growth and its policies and legal framework in Nigeria. The focus of the study was on the discussion of the country's legal aspects related to clean energy expansion and policies of the government of Nigeria. The study revealed potential policy-related challenges such as inappropriate economic incentives, unfavorable and exorbitant taxes, and tariffs to boost clean energy production. The researchers further suggested the changes in environmental laws and investment regulations by the Nigerian government provide impetus to the clean and efficient energy sector. Similarly, Kanellakis et al., (2013) documented the energy policies and union-related strategies which comprise renewable energy, energy efficiency, energy-related safety and security, and research and development. Another study in the context of Nigeria was conducted by Olugasa et al. (2014) who deliberated a discussion on the clean energy production from biogas and its utilization in the developing economy. The study provides comprehensive information on generating and storing biogas clean energy and directed its potential quantitative benefits on meeting demand and economic growth in developing economies. In addition, Pfeiffer and Mulder (2013) using a two-stage estimation technique examined the generation of electricity by the transmission of non-hydro renewable energy technology in 180 developing countries. The findings suggest the stringent regulatory and economic system escalate the transmission. Moreover, greater fossil fuel production and electricity consumption may defer the transmission of non-hydro renewable energy.

In a similar vein, Maji (2015) demonstrated the influence of renewable energy on economic growth in Nigeria by applying the autoregressive distributed lag (ARDL) and cointegration approach. The findings signal long-term inverse relationship between alternative energy sources and economic development. Moreover, the results unveil a substantial positive correlation between waste, explosive renewables, and economic development. In the short term, these relationships are found to have mixed evidence. Furthermore, Sbia et al. (2014) also employed the ARDL model and examined the relationship between renewable and non-renewable energy, foreign direct investment (FDI), economic growth, and trade openness in UAE. The findings conclude that FDI, CO_2 emission, and trade openness lessen energy consumption whereas economic indicators and renewable energy have a positive impact on energy use.

Simsek and Simsek (2013) uncovered the development and growth of renewable energy in Turkey. The results confirmed that incentives and improvements in clean energy legislations boost investment and economic growth opportunities in the country. Moreover, it is learned that renewable endowments such as wind, solar, and geothermal have captured attention across the globe and assisted economic progress. Another study by Pao et al. (2014) identified the association between renewable and unclean energy and economic growth of the sample of four countries, i.e., Mexico, Indonesia, South Korea, and Turkey. The researchers applied the panel cointegration approach and found long-run causality between economic growth and clean energy usage. Moreover, the researchers found that clean energy also has a long-term effect on fossil fuel consumption. Some of the recent studies such as Ohlan (2016) presented the comparative analysis on the impact of both renewable and non-renewable energy on economic growth in India. The researcher revealed positive causality between non-renewable energy sources and economic growth; however, it is concluded that economic growth may not be sustained for the long term based on traditional energy sources without switching towards clean energy options because of growing economic needs and consumption. Moreover, Maji et al. (2019) found that renewable energy usage lessens economic growth. Nonetheless, the researchers recommend opting for renewable energy generation sources while curtailing their adverse effects in West African countries.

In slightly another context, Brown et al. (2012) determine the six different notions on renewable electricity that are partially supported in the southern US. The research determined the latest policies on energy that can meet the growing demand of users and reduce the expenditures for both public and government till the next two decades. Besides, Perobelli and de Oliveira (2013) developed indicators for efficient energy growth using factor analysis in 27 Brazilian states. The analysis unveiled three indicators of potential energy development, i.e., demand for energy and supply of renewable and non-renewable energy. Yi (2014) determined the various factors accelerating the growth of the economy in 48 different states of the USA and identified that implementation of clean energy policy, green businesses, and stringent labor laws is a major factor of green business and economic development. Similarly, Lewis (2014) investigated the impact of cooperation between the USA and China in the production of clean energy resources. The researchers conclude that cooperation between these powerful countries can potentially boost economic growth, promote environmental quality, and reduce CO_2 emission. A recent study by Mangla et al. (2020) identified the potential indicators for a sustainable energy system in developing economies.

Prior studies in the context of clean energy and stock prices present interesting results. Linn (2006) investigated fluctuations in the prices of green energy companies' stocks which occurs due to the changes in prices of carbon and regulations related to the environment. Similarly, Henriques and Sadorsky (2008) documented the association between renewable energy, stock, and oil prices using the VAR approach. The findings suggest that stock prices of clean energy-producing companies are influenced by innovation in stock prices of technology. Moreover, oil price shocks have a less significant impact on renewable firms' stock prices. In a similar vein, Kumar et al. (2012) exhibited a significant favorable relationship between stock prices of renewable energy companies and oil prices. Managi and Okimoto

(2013) reckoned the association among clean energy, oil, and technology stock prices by employing Markov-switching vector autoregressive models. The findings imply that after witnessing structural breaks in 2007, there exists a favorable correlation between clean energy and oil prices. Moreover, the researchers concurred that the market reactions to both technology stock and clean energy stock are similar. Paramati et al. (2016) examined the association among inward FDI, stock market development, and renewable energy consumption in 20 developing and emerging economies. The findings provide evidence of the significant positive relationship among the said variables. Recently, Razmi et al. (2020) also found that the stock market and economic growth have a significant effect on renewable energies in the short and long run.

Although prior studies predominately focused on the nexus between financial development and economic growth (Ibrahim and Alagidede, 2018; Jamel and Maktouf, 2017; Murari, 2017; Nyasha and Odhiambo, 2018; Ono, 2017; Opoku et al., 2019) and on the growth-energy nexus (Baz et al., 2019; Ouyang and Li, 2018; Rahman and Velayutham, 2020; Saidi et al., 2017; Shahbaz et al., 2018), however, the relationship between financial development and energy consumption has only recently garnered attention. There are diverse views on the financial development-energy consumption nexus. According to one viewpoint, increased financial development could lead to increased energy demand. Indeed, financial development will increase energy consumption by (i) making financial resources more affordable and accessible, which can be used to grow existing businesses or start new ones; (ii) attracting foreign direct investment (FDI) inflows; and (iii) boosting consumer and business trust, resulting in increased economic activity and energy demand (Sadorsky, 2010; Tamazian et al., 2010; Zhang, 2011). Contrary to the first point of view, financial development could result in a reduction in energy demand by supporting the renewable energy sector and making innovative technology and environmentally friendly projects more accessible and less expensive (Gaies et al., 2019; Tamazian et al., 2009). Furthermore, FDI is an effective platform for technology transfer (Aziz, 2018), and foreign investors' technology could be superior to existing technology, reducing energy consumption (Hübler & Keller, 2010; Keller, 2004; Mielnik & Goldemberg, 2002).

Empirically, a few studies investigated the linkage between financial development and energy consumption, but the results are mixed or inconclusive. Some empirical studies, for instance, Sadorsky (2010) for 22 emerging countries, Xu (2012) for China, Shahbaz et al. (2013) for Indonesia, Çoban and Topcu (2013) for EU countries, Islam et al. (2013) for Malaysia, Ozturk and Acaravci (2013) for Turkey, Tang and Tan (2014) for Malaysia, Abosedra et al. (2015) for Lebanon, found the positive impact of financial development on energy consumption. On contrary, some studies found a negative or no association between financial development and energy use. Using panel data from 1990 to 2014 for 32 high-income countries, Topcu and Payne (2017) pointed out that as the stock market index rises, energy demand decreases slightly. However, no statistical association was observed between the overall financial development index and energy consumption. Shahbaz et al. (2016) investigated the relationship between globalization, financial development, and energy consumption in India over the period 1971–2012 and concluded that financial development and globalization lower energy demand. In a similar vein, Ouyang and Li (2018) found that financial development has a negative impact on energy consumption, resulting in a downward trend in consumption. Altay and Topcu (2015) show that there is no significant association between financial development and energy consumption in Turkey for the period 1980–2011 using cointegration and causality methodologies. Some of the studies applied causality and cointegration tests to investigate the nexus.

The stock market plays an important part in providing funding for renewable energy projects as well. An increase in a country's activities related to the stock market can increase economic growth, and an increase in economic growth can also affect energy demand (Sadorsky, 2010).

Similarly, Liming (2009) stated that the development of the stock market increases the availability of funds for clean energy projects and clean energy consumption. Sadorsky (2010) predicted that stock market developments would boost energy demand in emerging economies, while Chang (2014) reported that market capitalism would boost investment and energy consumption in emerging economies. Also, Abbasi and Riaz (2016) in an emerging economy and Dasgupta et al. (2001) in developing countries found a positive and significant relationship between energy consumption and stock market trading volume. Sadorsky (2011) also found Central Europe for the period 1996–2006. The results found that rise in stock market turnover to GDP raise energy demand in Central and Eastern European frontier economies. The ratio of stock market capitalization to GDP, as well as the ratio of stock market value traded to GDP, has been found to have no statistically significant association with energy demand. The variation between these figures reflects the fact that frontier economies have less mature capital markets than emerging markets. Chang (2014) conducted a study of 53 countries from 1999 to 2008 and discovered that in the high-income system, increased stock market growth decreases energy consumption in advanced economies while it raises energy consumption in emerging markets and developing economies. In a similar vein, Mahdi Ziaei (2015) uses PVAR modeling to investigate the impact of financial development variables shocks on energy consumption in European, Asian, and Oceanian countries. The findings show that stock market shocks have an impact on energy consumption, especially in Asian and Oceanian countries in the long run. In addition, Doğan et al. (2023) investigated the relationship between the Global Clean Energy Index, Carbon Emission Allowances, and the Istanbul Stock Market with the TVP-VAR method. As a result of the analysis, it was determined that Carbon Emission Allowances spread volatility to the Global Clean Energy Index and Istanbul Stock Market. In addition, the authors found that the spread of volatility among these variables decreased significantly during the COVID-19 pandemic period.

Researchers have paid growing attention to the relationship between financial development and energy use over the last decade (Khan et al., 2021; Wang et al., 2021; Shahbaz et al., 2021; Pata et al., 2022). However, the postulation of whether clean energy augments stock market development has garnered little attention. Stock market performance can be perceived as a sign of economic growth and development, which in turn boosts consumer and business confidence. Increased economic optimism boosts economic growth and drives up energy demand. As can be seen from the preceding discussion, empirical studies produce inconsistent outcomes as a result of various econometric methodologies, different indicators of financial development and/or energy consumption variables, and the economic development levels of the countries/regions studied. This merits further scrutiny to investigate the relationship between clean energy and stock market development in the context of China.

Data and Econometric Methodology

We have measured stock market development for both the Shanghai and the Shenzhen stock markets via stock market capitalization as a percentage of GDP. The stock market capitalization is a well-known proxy for measuring growth in the stock market (Garcia & Liu, 1999; Yartey, 2010). Similarly, liquidity for both markets is proxied by stock value traded as a percentage of GDP. Clean energy has been measured as alternative and nuclear energy as a percentage of total energy use. Banking sector development represents credit to the private sector by banks (percent GDP). Savings and trade openness have been measured through gross domestic savings to GDP and the ratio of exports and imports to GDP, respectively. To accomplish the objective of the study, we have utilized data for the period 2006 M1 to 2020 M12. The data period is defined by the availability of monthly data for all the variables included in this study. All the data for the above variables have been sourced from the CEIC database.

The wavelet coherence approach of Torrence and Webster (1999) captures changes between variables at different intervals over a span of time. This approach pinpoints the event frequency on a local basis, i.e., local time which enables us to identify peculiarities associated with the time series data. The standard time series approaches use the time-domain framework, overlook information on the frequency aspect, and ignore nonlinearities (Serroukh et al., 2000; Manimaran et al., 2009; Huang et al., 2016). The wavelet analysis identifies the regime-switching behavior and determines the short-run and long-run dynamics between variables in both the time and frequency aspects (Chowdhury et al., 2021). The time-varying co-movement between two variables with their cross-wavelet transform can be written as

$$W_{x,y}(o,p) = W_x(o,p)W_y^*(o,p) \tag{1}$$

The operators $W_x(o,p) = W_y^*(o,p)$ are continuous wavelet transforms of $x(t)$ and $y(t)$, whereas o and q represent location index and scale, respectively. The symbol (*) stands for the composite conjugate.

The wavelet coherence approach (WCA) assesses correlation and covariance between two variables across different times and frequencies (Torrence & Compo, 1998). In other words, WCA evaluates covariance between $x(t)$ and $y(t)$ at each scale. Taking insights from the inferences drawn by Torrence and Webster (1999) and Compo (1998), the coefficient of squared wavelet coherence (WSC) equation can be written as follows:

$$WSC = W^2(o,p) = \frac{|M(M^{-1}Wop(o,p)|^2}{M\left(M^{-1}\left|W_a(o,p)\right|^2\right)M\left(M^{-1}|W_b(o,p)|^2\right)} \tag{2}$$

where M represents the time-frequency smoothing mechanism. The squared wavelet coefficient falls within the range of 0 and 1, where a value closer to one exhibits robust correlation and the value closer to 0 represents weak correlation. The operator $W^2(o,p)$ is synonymous to the conventional correlation coefficient with $0 \leq W^2(o,p) \leq 1$. Owing to the wavelet squared coefficient phenomenon, the WSC does not recognize negative values and is limited to positive values, which does not clarify the direction of time series. To rectify this issue, we resort to the phase difference process of (Torrence & Compo, 1998), which determines the direction of co-movement between two variables. The phase difference equation can be expressed in mathematical form as below:

$$\phi_{XY}(o,p) = tan^{-1}\left(\frac{lm\{M(m^{-1}W_n^{xy}(o,p))\}}{Re\{M(m^{-1}W_n^{xy}(o,p))\}}\right) \tag{3}$$

where lm and Re are real and imaginary parts of smoothed cross-wavelet (XWT) transforms, respectively. The cross-wavelet coherence outcome is generally pictorial. Phases ϕ_{XY} are denoted by arrows. These arrows underscore the causal direction between two time series. Arrows pointed towards the right and left side delineate in-phase (positive) and out-phase (negative) associations between the two variables. The upright and down-left arrows exhibit that the second series is following the first series and the other way around. The coherence region is defined by the black curve in the WSC plot, and the bell-shaped solid line is the cone of influence.

Breitung-Candelon Frequency Domain Causality

To determine short-, medium, and long-run causalities among variables, we resort to the frequency domain causality approach pioneered by Breitung and Candelon (2006). This approach delineates causal associations between variables. The feature that distinguishes frequency domain approach from the time-domain approach is that the frequency domain approach is capable of determining the degree of specific variations in time series settings, whereas the time-domain approach gauges the specific changes that occurred within a specific period. The frequency domain approach highlights nonlinearities and stages of causality, i.e., short, medium, and long run.

Results and Discussion

The stochastic properties of the variables included in this study have been reported in Table 1. The range of both the Shanghai and the Shenzhen stock markets are from 14.728 to 17.634 and 14.655 to 18.162, respectively. The value of kurtosis for most of the variables exceeds 3, which indicates the nonlinear behavior of the variables. The probability values corresponding to the Jarque-Bera

Table 1 Descriptive analysis

	SMDSH	SMDSZ	SMLSH	SMLSZ	CE	BSD	TO	SAV
Mean	16.743	16.621	12.853	12.531	9.505	11.468	3.849	3.955
Median	16.712	16.487	12.853	12.393	6.881	11.193	3.765	3.956
Maximum	17.634	18.162	14.273	14.282	27.614	15.239	5.373	4.257
Minimum	14.728	14.655	11.233	10.673	4.583	8.499	2.882	3.665
Std. Dev.	0.588	0.932	0.565	0.815	6.816	1.905	0.775	0.190
Skewness	−1.431	−0.219	0.083	0.124	1.736	0.165	0.574	−0.031
Kurtosis	5.647	2.061	3.077	2.109	4.516	2.127	2.211	1.572
J-B	113.972	8.055	0.250	6.416	107.677	6.534	14.552	15.315
Probability	0.000	0.018	0.882	0.040	0.000	0.038	0.001	0.000

Probability values correspond to the Jarque-Bera statistics

test show all the variables have a non-normal distribution except for the Shanghai stock market liquidity. These outcomes guide us to employ asymmetric approaches such as the wavelet coherence approach. Regarding other stochastic properties, the rest of the variables have level-headed descriptions.

To further strengthen the foundation of the model, we utilize the Kruse (2011) nonlinear unit root test. This nonlinear test takes a two-pronged approach: (a) it evaluates the stationarity of the variables, and (b) it identifies potential nonlinearities in the data series. Table 2 reporting the results of the Kruse (2011) test suggests that we can reject the null hypothesis for all the variables in our model, as their corresponding *P*-values are less than 1% and 10% significance levels, respectively. These findings infer that the model exhibits stationarity with nonlinear characteristics.

The wavelet coherence outcomes are pictorially obtained. In these figures, importance is given to the results inside the cone, and the significance is defined by the black contour inside the cone obtained via the Monte-Carlo simulation (Figs. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10). Figures 1 to 10 represent the coherence between clean energy and the Shanghai/Shenzhen stock market development. These figures infer that at different scales, majority of the arrows are in-phase which underscores the positive association of clean energy towards the growth of both financial markets. The direction of the arrows in the black contour in both figures is moving towards the right side at various frequencies, which entails the positive correlation between clean energy and the Shanghai/Shenzhen stock market development. These outcomes validate the main postulation that clean energy and stock market development have causal relationship. These results are supported by the fact that China is now a leading country in terms of international renewable investments (REN21). Specifically, China has taken lead from other countries in terms of capacity per capita of renewable energy sources efficiency in geothermal and hydropower energy production. According to 2018 estimates, China's investment pertaining to renewable energy sources was approximately 92.2 US billion dollars, the largest investment in the world followed by Europe ($61.2 billion) and the United States ($48.5 billion) standing second and third in terms of renewable energy investment in the world. Such huge investments

Table 2 Kruse nonlinear unit root test results

Level	SMCSH	SMCSZ	SMLSH	SMLSZ	CE	BSD	TO	SAV
Raw data	−0.0001***	−3.0350	−1.6130*	−1.9531	−5.9160	−3.5860	−0.0003	−0.0001
Demeaned data	0.0003	0.0127**	−2.9121	−3.4601*	−0.0003*	−0.0008*	−0.0013*	−0.1376*
Detrended data	−0.1034**	−0.7302**	−3.8021	−7.2691*	-0.0026**	−0.0001***	−0.2232*	−0.8498*
1st difference								
Raw data	0.1501*	1 0.1560	−4.9440	−3.0040	2.6890	6.8550	0.0006	−0.0005
Demeaned data	0.1448***	0.1406***	−2.994***	−2.0850*	0.0249*	0.0058*	−0.0148*	−0.0246*
Detrended data	0.2113**	0.1632*	−3.0000***	−2.442**	0.0794**	0.0994*	−0.0949*	−0.0149*

***, **, and * denote significance at 1%, 5%, and 10% levels, respectively

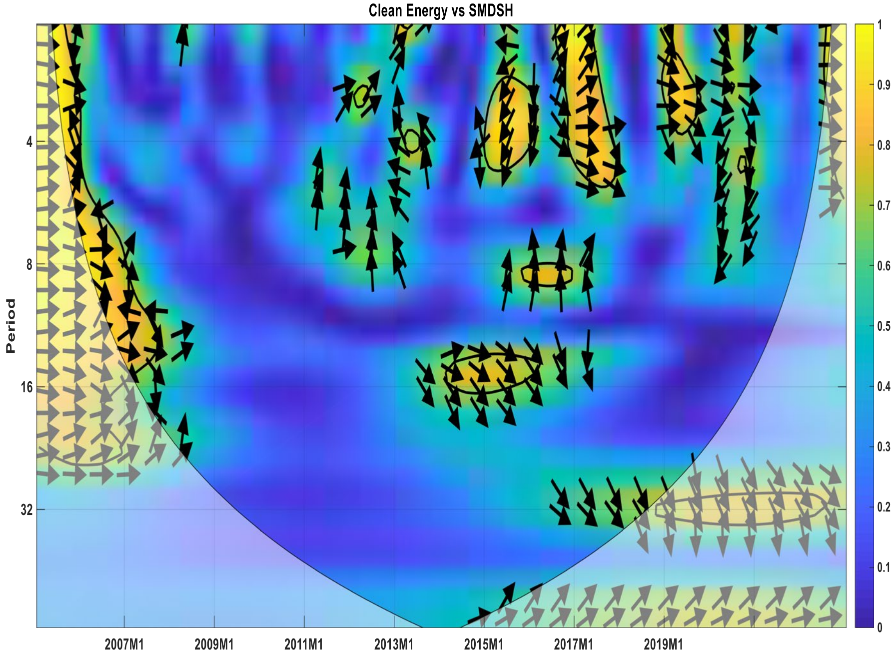

Fig. 1 Coherence between clean energy and Shanghai stock market development

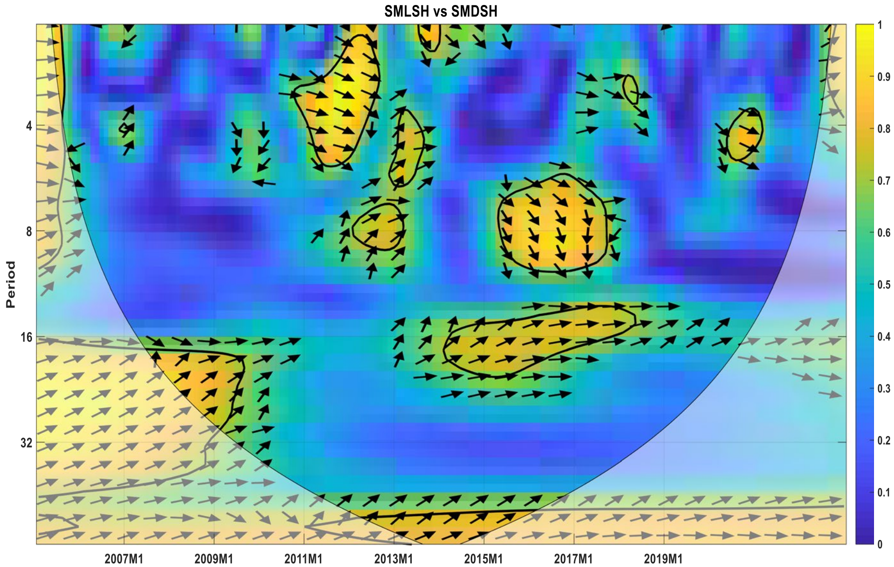

Fig. 2 Coherence between Shanghai stock market liquidity and Shanghai stock market development

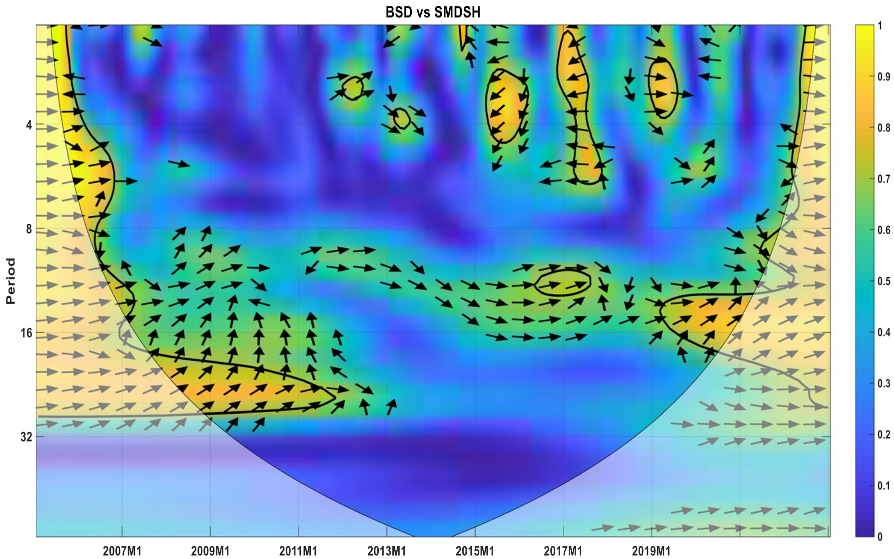

Fig. 3 Coherence between banking sector development and Shanghai stock market development

on behalf of China espouse novel investment avenues and have favorable impact on the size of stock markets in China.

The correlations between stock liquidity for the Shanghai and the Shenzhen stock markets and the size of both financial markets were observed to be in positive relationship, particularly in the medium and long-term across different scales. These outcomes infer that liquidity plays a prime role in pushing the envelope of the size of both stock markets in China. Liquidity characteristics of stock markets bolster economic activities owing to the ease of buying and selling stocks, enabling them to grow further. The extant literature supporting the view that stock liquidity propels the size of the stock market includes Ben Naceur et al. (2007); Demirgüç-Kunt and Levine (1996); Garcia and Liu, (1999); and Ullah et al. (2020) (Fig. 7). Figures 3 and 8 depict the relationship between banking sector development (BSD) and the Shanghai and Shenzhen stock market development. We have noticed both positive and negative associations between BSD and both financial markets at different times and frequencies. The literature also affirms these mixed results. BSD and stock markets complement each other as they concurrently exhibit growth and move in the same direction (Boyd et al., 2001; Yartey, 2010). The negative relationship between BSD and the stock market lies in the fact they play substitution role as both entities compete for limited resources. We observed that trade openness augments Chinese stock markets as majority of the arrows in the significance area are moving straight towards the right side for stock markets. Augmented trade openness entices more foreign capital inflows and offers the benefits of risk diversification; this, in turn, attracts more investment towards the stock market. Promoting trade openness not only enables government to increase the size of the stock market but also assists the

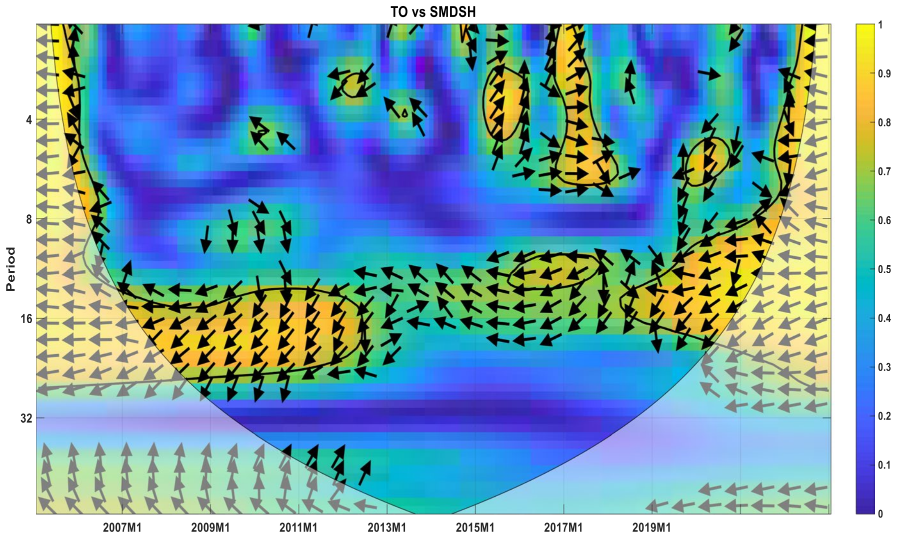

Fig. 4 Coherence between trade openness and Shanghai stock market development

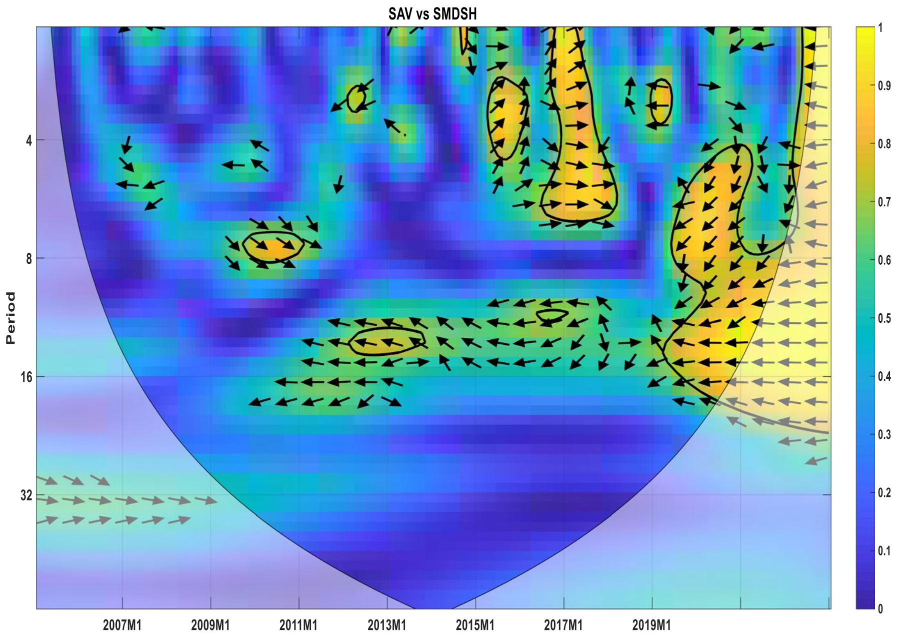

Fig. 5 Coherence between savings and Shanghai stock market development

highest authorities to build stable and prosperous economy. We also observed negative association between trade openness and Chinese stock markets growth in some time and frequencies. One plausible reason for this outcome may be that

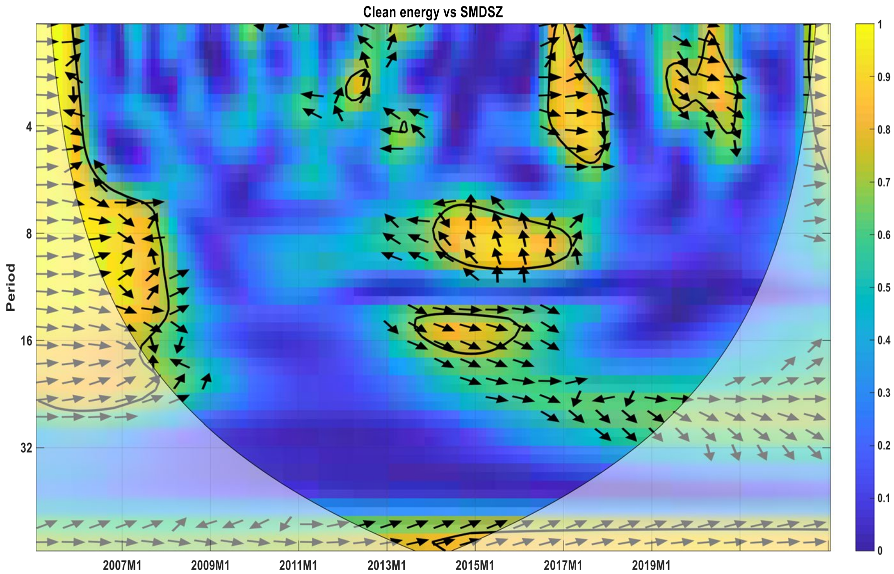

Fig. 6 Coherence between clean energy and Shenzhen stock market development

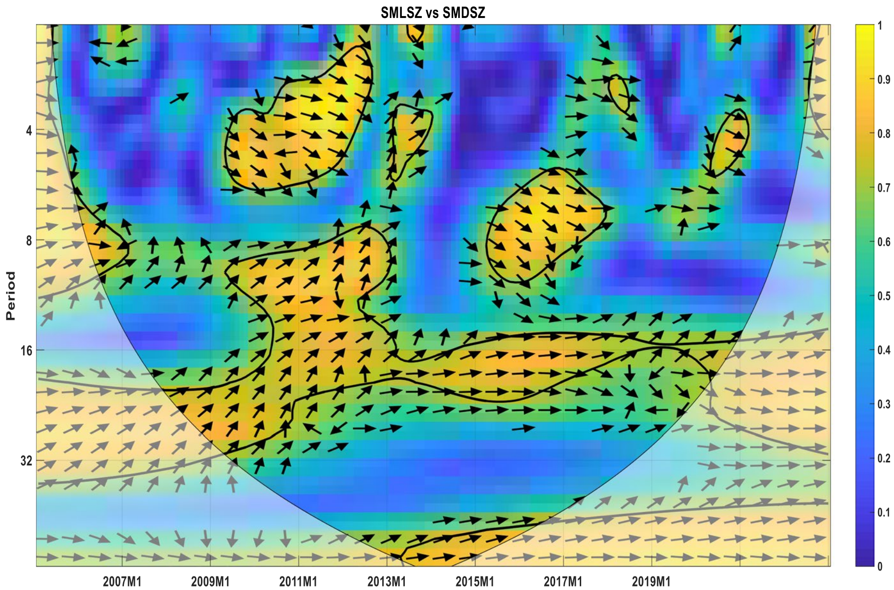

Fig. 7 Coherence between Shenzhen stock market liquidity and Shenzhen stock market development

trade openness sometimes affects the stock market through portfolio investment (Fig. 9) (Shahbaz et al., 2016). Figures 5 and 10 indicate that savings and stock market development in China are positively related. Savings augment the size

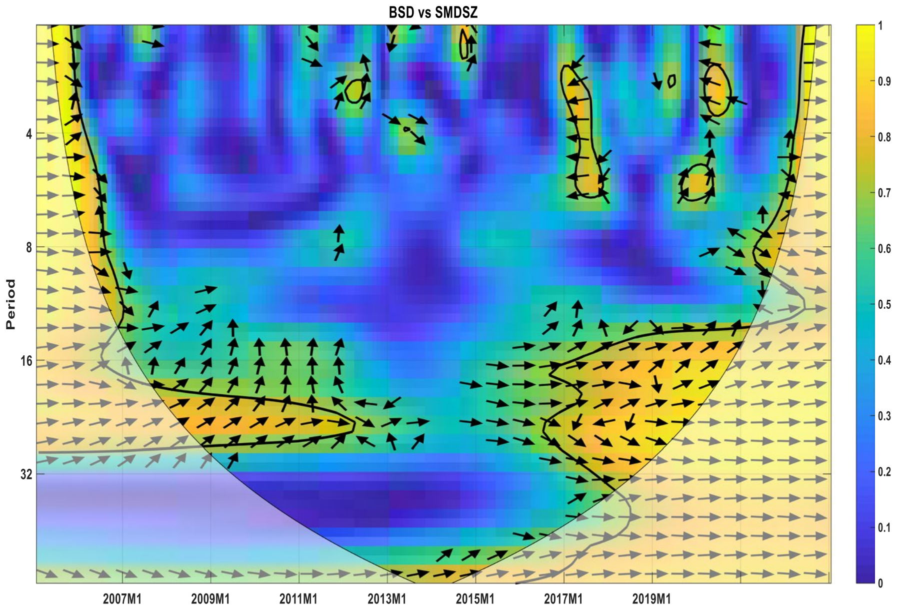

Fig. 8 Coherence between banking sector development and Shenzhen stock market development

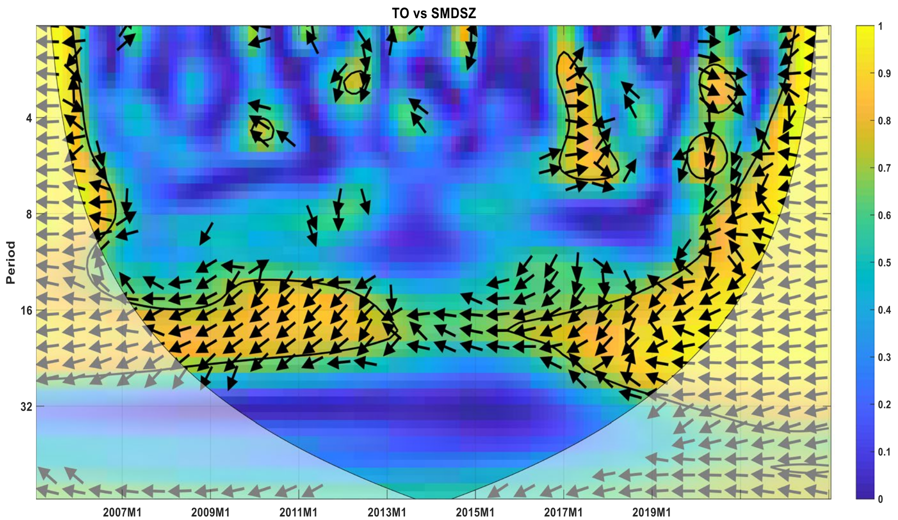

Fig. 9 Coherence between trade openness and Shenzhen stock market development

of stock markets and channelize savings to investment projects. In the literature, these findings are congruent with the findings of Yartey (2010) and Garcia and Liu (1999).

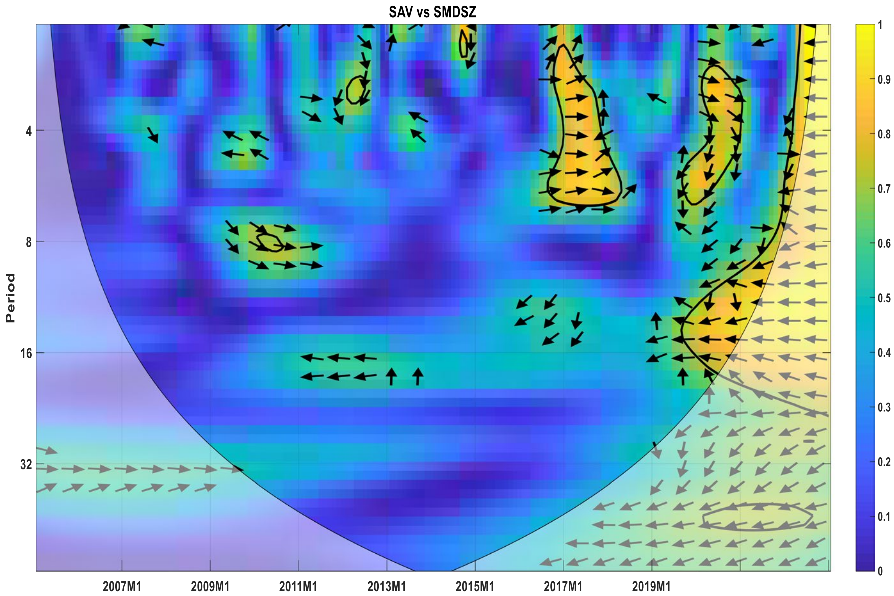

Fig. 10 Coherence between savings and Shenzhen stock market development

Breitung-Candelon Spectral Causality Approach Results

Subsequent to exploring the causal associations between clean energy and other factors influencing the size of stock markets in China in time and frequency domain perspective, we have further utilized the Breitung–Candelon frequency domain spectral causality test to determine the causality among the above variables. Such an exercise will further validate our main estimations obtained via the wavelet coherence approach. In the spectral causality approach, the significance is depicted by two straight lines. These lines correspond to significance level of 5% and 10%, respectively (Figs. 11, 12, 13, 14, 15, 16, 17, 18, 19, and 20). The statistical test is depicted by a curve for various frequencies between the interval of (0, π). Figures 11 and 16 illustrate that clean energy has a lead-lag relationship with the Shanghai and the Shenzhen stock market development in the short and medium term. These outcomes imply that China's stock market growth is responsive towards clean energy and proper measures should be taken to develop the clean energy sector to propel the size of the stock market in China. The spectral causality further affirms that much like the clean energy both the Shanghai and Shenzhen stock markets growths exhibit sensitivity towards liquidity, banking sector development, trade openness, and savings in the short, medium, and long run. In this regard, the higher authorities should consider the importance of these factors in relationship with stock market growth in China.

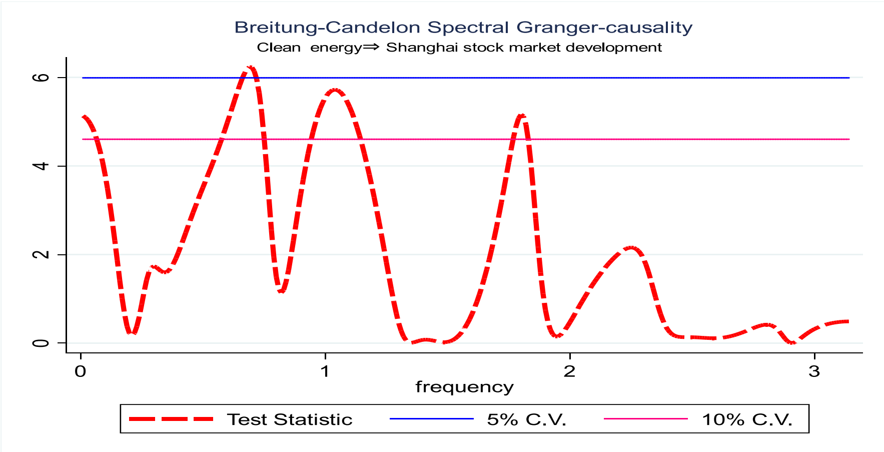

Fig. 11 Clean energy has a lead-lag relationship with the Shanghai stock market development

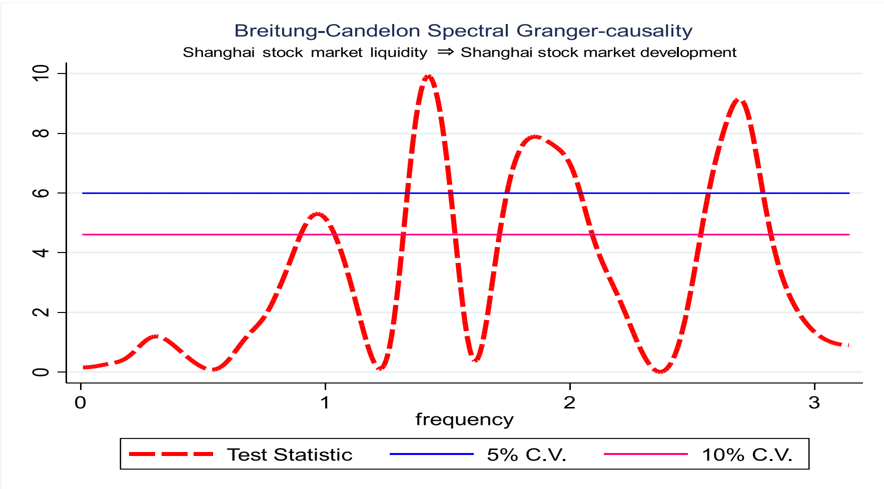

Fig. 12 Shanghai stock market liquidity has a lead-lag relationship with the Shanghai stock market development

Concluding Remarks

The stock market is considered to be a cardinal element of economic growth as it bridges the gap between savings and investment. This study explored the asymmetric impact of clean energy on China's stock market development, utilizing the wavelet coherence and spectral causality approaches for the period spanning 2006 M1 to 2020 M12. The outcomes reveal that the Chinese stock market exhibits growth with respect to clean energy. These outcomes appeal that clean energy projects are

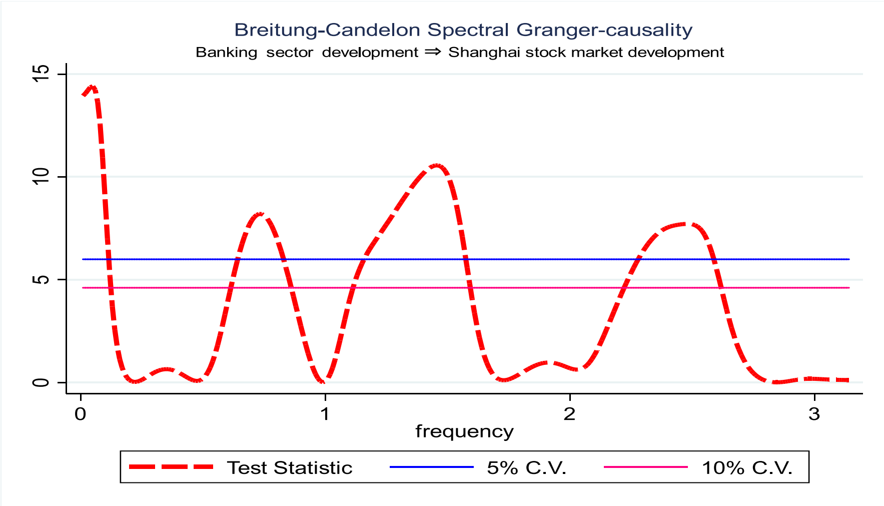

Fig. 13 Banking sector development has a lead-lag relationship with the Shanghai stock market development

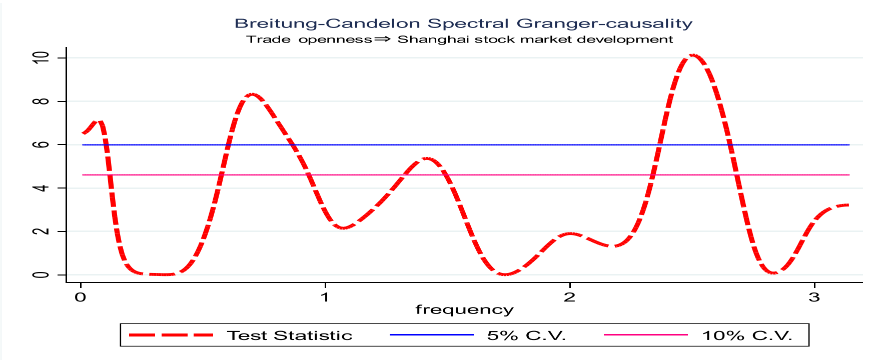

Fig. 14 Trade openness has a lead-lag relationship with the Shanghai stock market development

vital to the development of the stock market in China as they will modernize the energy sector by opening up new investment avenues and at the same time enable the Chinese authorities to achieve sustainable growth. The heavy reliance of China on dirty (non-renewable) energy has engendered severe environmental issues. Based on the outcomes, we suggest that the Chinese authorities should give preference to clean energy rather than dirty energy as clean energy projects tend to curtail carbon emissions, the reduction of which is the biggest challenge to China to achieve millennium development goals. Energy is a prime source of social well-being and economic prosperity concurrently espouses global warming issues. Investment in clean energy technologies may enable the government to appease global warming and achieve sustainable growth. The introduction of clean energy projects can also pool

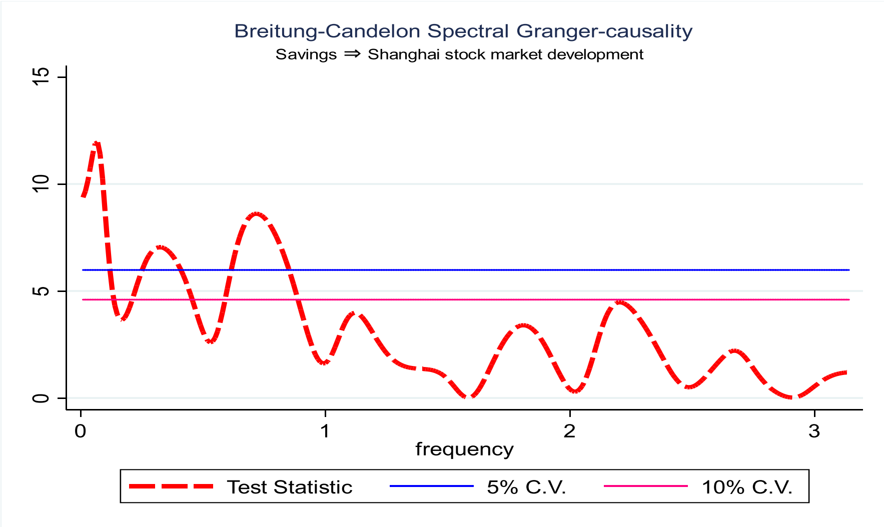

Fig. 15 Savings has a lead-lag relationship with the Shanghai stock market development

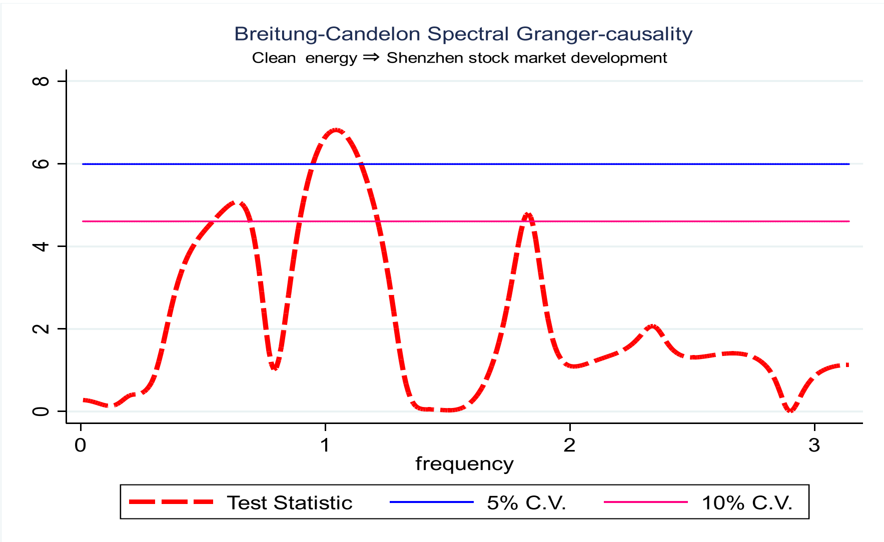

Fig. 16 Clean energy has a lead-lag relationship with the Shenzhen stock market development

huge investments as the investors deem such projects to be environment friendly consequently boosting stock market growth in China.

The increase in stock market activities creates a wealth effect by increasing the confidence level of investors and businesses. As a result of such effects, investment initiatives tend to increase. Likewise, the development and growth of the stock

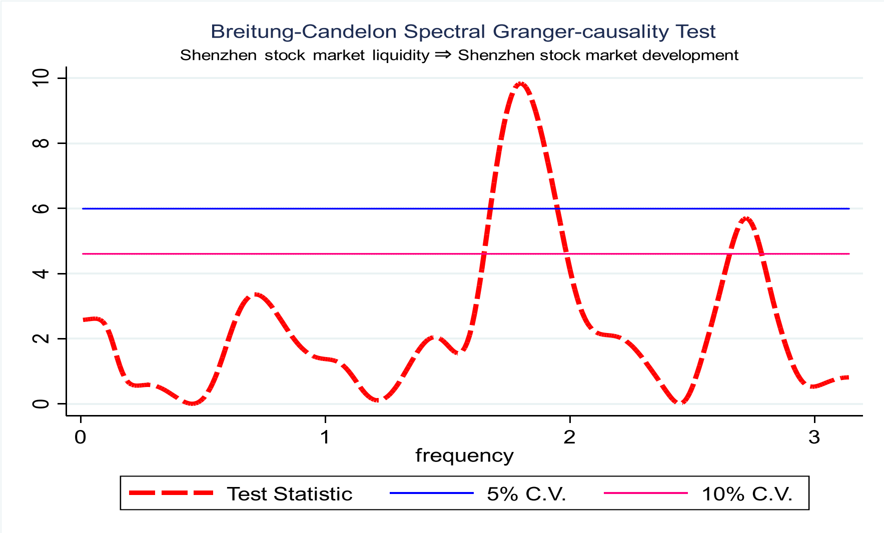

Fig. 17 Shenzhen stock market liquidity has a lead-lag relationship with the Shenzhen stock market development

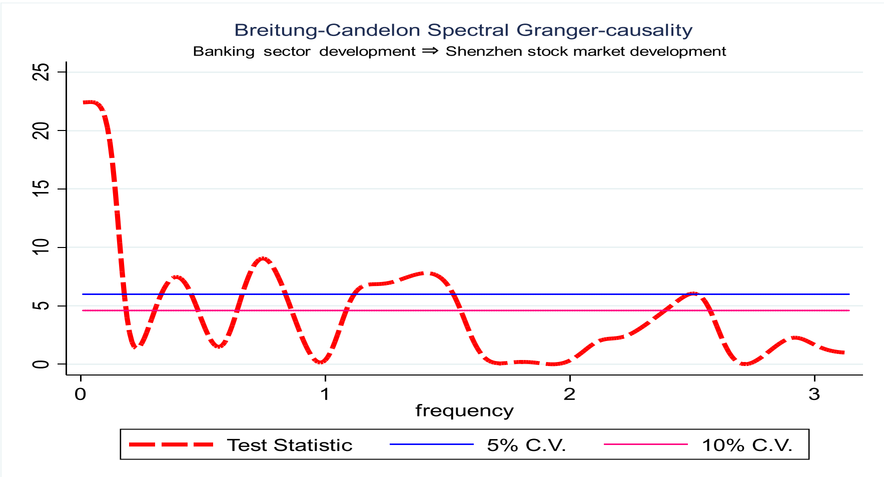

Fig. 18 Banking sector development has a lead-lag relationship with the Shenzhen stock market development

market make access to financial assets easier for clean energy-related businesses. Increasing green financing for clean energy projects may have an impact on the Chinese stock market development. In addition, it is suggested that the Chinese government provide incentives to transfer financial assets to clean energy investments. It

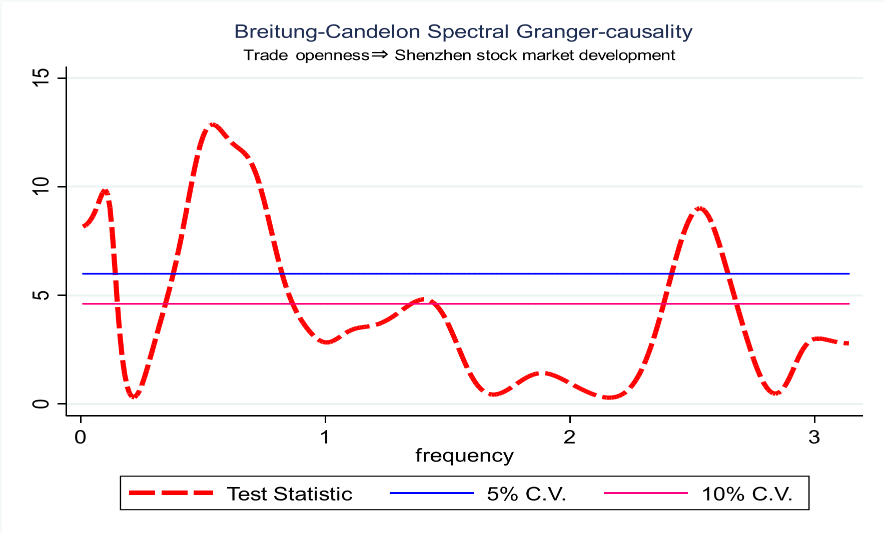

Fig. 19 Trade openness has a lead-lag relationship with the Shenzhen stock market development

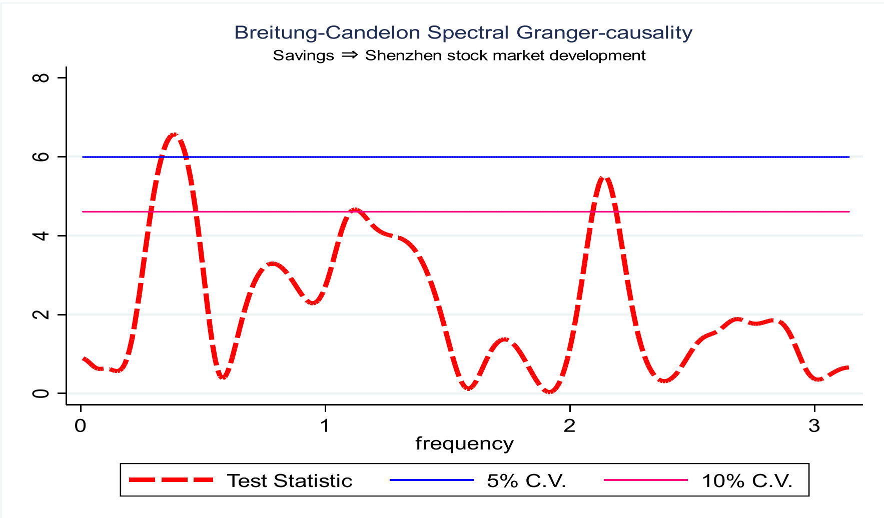

Fig. 20 Savings has a lead-lag relationship with the Shenzhen stock market development

should increase in human capital investments, and it would be useful to take necessary measures to determine strategies for clean energy investments and projects.

The outcome of this research work gives further insights to the Chinese policymakers to devise green financial policies by supporting clean energy investment. The public funding also supports companies utilizing clean energy. Introduction of the supportive policies in the shape of subsidies for firms using clean energy will also augment the prices of the clean energy stocks. Policy decisions pertaining to the transition from dirty energy to clean energy will give rise to a decarbonized economy. The cost of capital for clean energy projects should also be lowered as their initial cost ten be high. Such measures will eradicate environmental hazards in China and improve overall public health thereby enabling China to achieve sustainable development goals. The study has potential implications for policymakers and energy investors to better manage and hedge the risks in the stock market, and it will also be of interest to investors investing in green energy stocks. Specifically, our outcomes will guide environmentally friendly investors to design green investment portfolios that will offer them alternative hedging strategies. This research also evidenced that liquidity, banking sector development, savings, and trade openness intensify the stock market growth. To enhance the depth of the stock market, policymakers should design policies that not only ensure adequate liquidity but should also enhance the workings of economic institutions.

Limitations and Future Research Directions

This research work suffers from some limitations. The empirical outcomes of our study can be further improved by combining wavelet coherence with non-parametric causality in quantiles approaches which will highlight the asymmetric correlations across different quantiles. The prime motive behind studying the case of China is the severe environmental pollution challenges confronted by the country and the recent practical steps taken by the government in utilizing clean energy to realize green economy targets. Future research should explore the nexus between clean energy and stock market development in terms of other emerging and developing economies as majority of these countries are confronted with environmental malaise and the outcomes of this study may serve as a guide to them to increase the size of the stock markets by attracting more investment population towards clean energy projects. This research work can be further extended through the application of novel time series methodologies such as the quantile-on-quantile regression and quantile causality approaches to highlight the full distribution relationship between clean energy and the Chinese stock market, revealing any asymmetric relationships. We hope to cover these gaps in our future work.

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Data Availability Data is available from the corresponding author upon reasonable request.

Declarations

Ethics Approval Not applicable.

Consent to Participate Not applicable.

Consent for Publication Not applicable.

Competing Interests The authors declare no competing interests.

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