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Nexus between green financing, economic risk, political risk and environment: evidence from China

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ABSTRACT

This study provides fresh evidence regarding the dynamic association that is believed to exist in relation to green finance (GF), economic growth (GDP), political risk (PR), economic risk (ER), and carbon dioxide (CO_2) emissions. It therefore uses the dataset pertaining to China from most recent time-series – covering the period spanning from the years of 1990 to 2020, by employing the Morlet Wavelet Analysis technique. The empirical findings of the wavelet power spectrum reveal that green finance GF and ER are vulnerable in the short- and long-run, and the short-run, respectively. At the same time, no vulnerability has been observed in the GDP, PR, and CO_2 emissions. In addition to this, the wavelet coherence also reveals the bidirectional causal association that exists between GF-CO_2 and ER-CO_2, but only in the short run. It must also be taken into consideration that the causal influence of CO_2 is deemed to be greater than the GF and ER, respectively. Besides this, a bidirectional causal nexus also exists between the GDP and CO_2 emissions, only in the long run. Furthermore, the association between the economic growths follows both the phase and antiphase associations. Moreover, the study also reveals that there is no significant causal link between the PR and CO_2 emissions. The results emphasize that the significance of green finance investment will tend to increase with strict policy implications, stabilization or minimization of economic risk and political risk. The same will also take place while promoting environmentally friendly production via economic growth, so as to reduce CO_2 emission in the region taken into account.

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1. Introduction

The economic development behavior of merely chasing and maximizing profits has gradually faded from its historically prioritized position, with the advancement, development and awareness of the society. In the recent times, concepts such as green finance, environmental finance, and sustainable finance are the types of financial strategies that are deemed to be concentrating on environmental protection and

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sustainable development, and have also gained widespread acceptance and importance (Wang, Zhang, et al., 2021; Yu et al., 2022). Regarding the green finance transmission mechanism, research that is taking place in developed nations is frequently conducted from a market approach, and pays close attention to the market dynamics that are being cultivated and nurtured. The financing provided by investors, and the use of shareholders' right to vote tend to directly impact the decision-making of the company, thus directing or encouraging the growth of green finance. However, in emerging nations such as China, green financing is frequently channeled through government departments and associated financial institutions, in order to promote policy (Wang, Zhang, et al., 2021; Yan et al., 2021). Irrespective of the green finance transmission mechanism and development, acknowledging the green financial system construction, evaluating the green finance developmental level, the green financial system framework improvement, and incentive policies are all urging challenges that must be taken into account and addressed.

Recently, a novel idea pertaining to a green bond has attracted more attention, and has noticeably experienced a certain level of development in China (Zhang et al., 2019). In this regard, China is believed to have issued 144 green bonds, for a total of 267.6 billion yuan in the year 2018 alone. Moreover, it has also gained its reputation to be among the world's major green bond markets. Moving on in the same context, Green loans in China have totaled to 8.23 trillion yuan in the year 2018, thus amounting to 14.2 percent of the total loans that were borrowed from firms and other entities over the same time. It is noteworthy that the concept of Carbon financing arrived late in China. However though, it experienced a rapid surge in its growth. China has been conducting carbon emission trading pilots in seven of its cities and provinces since the year 2011. The combined trading volume of these pilot carbon markets reached to a staggering amount of 200 million tons by the year 2017, with a cumulative transaction volume of 4.7 billion yuan (Zhu et al., 2020) Currently, China is amongst one of the biggest financing markets for carbon.

In the last 4 decades of reform and opening up, China's economy has transformed from a high-speed growth stage, to a high-quality stage, with people's living conditions substantially improving, and the structure of the industry-changing dramatically (Meng et al., 2018). However, the ongoing industrial structure optimization is accompanied by a high quantity of carbon dioxide (CO_2) emissions. This has thus caused grave environmental concerns, and has put China to the test on its path to sustainable growth (Chen et al., 2017). Emissions of CO_2 have long been the focus of global climate change studies. In this regard, Svante Arrhenius, a Nobel laureate, predicted in 1896 that burning fossil fuels would raise the CO2 levels in the atmosphere, therefore resulting in global warming (Arrhenius, 1950). Since then, many researchers' subsequent investigations have corroborated the same results (Bosah et al., 2021; Malik et al., 2020; Song, 2021; Yang et al., 2021; Zhang et al., 2021). In the face of global warming, China has pledged to reduce CO_2 emissions per unit of GDP, by 40-45 percent, relative to the levels experienced in 2005. On the other hand though, (Ma et al., 2019) claimed that the CO_2 emission in China will reach their peak by the year 2030. As a result, one of the most pressing challenges that China must address is that of adapting its industrial structure and economic activities, so as to meet the objective of reduced emissions. Moreover, the long-term national economic growth plan also includes this goal, now as a mandatory criterion. Conversely though, during the Communist Party of China's Eighteenth National Congress, the government was committed towards doubling the GDP levels in China in the year 2020, relative to the year 2010 (Yang et al., 2017). Nonetheless, because economic expansion necessitates increased energy consumption, which results in increased carbon emissions, the Chinese government is expected to find it incredibly difficult to fulfill this win-win aim under the current technological conditions.

Moreover, global warming and CO2 emission are linked to economic growth or development and associated economic and political risks (Adams et al., 2020). Global uncertainties have increased the volatility of economic and political policies throughout the world. Clearly, any source of uncertainty (whether social, political, conflict, trade, or war) will have an impact on economic activity (Blattman & Miguel, 2010; Guidolin & La Ferrara, 2010). Economic policy influences the climate wherein firms operate, which in turn affects economic entities' decision-making. Because CO_2 emissions are related to company production choices, economic uncertainty or risk might impact CO_2 emissions. In this regard, (Jiang et al., 2019) claimed that economic policies affect CO_2 emission via direct government policy, which could either enhance or reduce environmental degradation. Similarly, the instability in the political conditions of the country could affect the investors decision-making. If the political instability increases in a region, the investors and manufacturers could postpone investing and production activities, which could affect environmental conditions. Therefore, it is the need time to empirically address these issues while considering environmental degradation such as climate change and global warming.

The primary objective of this research study is to empirically investigate the causal association between green finance and CO_2 emission. Although the literature extensively provides empirical estimates regarding the specific influence of green finance on environmental quality. Still, an in-depth investigation of the causal nexus between these variables is missing, which is necessary to identify. Secondly, this study analyzes the causal nexus of economic growth and political risk with CO_2 emission. Many studies have provided empirical evidence regarding the influence of economic growth and political risk on environmental quality (Bosah et al., 2021; Lee & Chen, 2021; Malik et al., 2020; Song, 2021; Su, Khan, et al., 2021; Su, Umar, Kirikkaleli et al., 2021; Su, Umar, et al., 2021; Su et al., 2020; Umar et al., 2020a; Wang, Su, et al., 2021; Yang et al., 2021; Zhang et al., 2021). Still, these studies have provided mixed and contradictory findings, which further require empirical investigation. Thirdly, there is extensive literature regarding the impact of economic policy uncertainty, yet they ignored the role of economic risk in environmental quality. Therefore, the current study aims to empirically investigate the causal association of economic risk and environmental quality. In order to achieve the aforementioned objectives, this study utilized a novel Morlet wavelet approach, which considers the time-frequency domain and provides short-run and long-run causal estimates.

This study is novel and contributes to the existing literature by threefold: firstly, this is among the pioneering study that empirically investigates the causal association of green finance and CO_2 emission along with the economic growth and political risk. Secondly, although the literature is extensively provided regarding economic policy uncertainty (Adams et al., 2020; Anser et al., 2021; Syed & Bouri, 2021), economic risk has been ignored in the case of China. Therefore, the current study provides empirical estimates for the said variable to fill the existing gap in the literature. Lastly, this study utilized the most updated dataset for the mentioned variable, which could provide innovative policy insights in the present time.

The rest of the study is organized as follows: Section-2 provides relevant literature review – covering all the variables under consideration; Section-3 represents data and methodology set up for empirical estimation; Section-4 indicates empirical findings and their discussion; Section-5 provides conclusion and policy implication.

2. Literature review

The emission of CO_2 in almost all parts of the world has created fear among the governors and policymakers regarding climate change and environmental degradation. This attracts the attention of scholars and researchers to empirically investigate the issue and provide practical policy insights. In this regard, extensive literature has been provided which considers various economic and non-economic variables to identify their influence on environmental degradation. Some of the prominent variables such as economic growth, green finance, political risk, and economic risk in relation to the CO_2 emission are provided in this section.

Specifically, most of the existing studies considered the nexus of economic growth and environmental quality. The most recent study of (Song, 2021) investigated 30 Chinese provinces over the period 2001-2016 and employed a threshold regression model with a fixed effect. The estimated results unveil that economically stable and developed province with a sustained high level of technological investment tends to reduce CO_2 emission in the region. However, provinces with lower economic growth and a lack of technology investments are more exposed to environmental degradation. On the contrary, (Yang et al., 2021) identified the role of economic growth and population in a low-carbon development for 78 countries throughout 2000-2017. The empirical findings reveal that economic growth and population expansion promote CO_2 emissions, while technological progress, production efficiency, and energy structure optimization significantly lead to a low-carbon economy. Using pooled mean group-autoregressive distributed lags (PMG-ARDL) model, (Bosah et al., 2021) investigated a sample of 15 countries between 1980 and 2017. Estimated results unveil that energy consumption promotes CO_2 emission in both the short and long run, while economic growth enhances CO_2 emission only in the long run. In case of China, (Zhang et al., 2021) analyzed data between 1965 and 2019 via employing Granger causality test. The estimated findings reveal that economic growth is critical for the environment. The authors argued that economic growth is the major reason for CO_2 emission. Using ARDL and non-linear ARDL approaches, (Malik et al., 2020) investigated Pakistan over the period 1971-2014. The study concludes that economic growth and foreign direct investment (FDI) intensify CO_2 emission in both the long and short run. At the same time, CO_2 emission decreases with increase in prices and vice versa. Besides, the study reveals that there is a bidirectional causal association between CO_2 emission and economic growth.

(Safi et al., 2021) analyzed seven emerging economies over the period 1995-2018 and employed second generation and third generation panel data methodology. The estimated results reveal that economic growth and imports significantly increase In the case of BRICS economies, (Banday & Aneja, 2020) investigated 1990-2017 period by using causality methods. The findings reveal that unidirectional causality from economic growth to CO_2 emission for countries except for Russia. Besides, this study validates the growth hypothesis for Brazil, Russia, India, and China. On the other hand, (Wang & Zhang, 2020) illustrate that enhancement in the research and development investment could help decouple economic growth from CO_2 emission. However, economic activities, urbanization, and industrialization weaken the decoupling of economic growth from CO_2 emission in the BRICS economies. For the same country, (Dong et al., 2020) investigated dynamic structural up-gradation, economic growth, and CO_2 emission reduction and conclude that a long-run equilibrium relationship exists between these variables. The authors further argued that CO_2 emission reduction enhances industrial structural up-gradation – which furthers economic growth. Similarly, economic growth and industrial structure up-gradation negatively influence on CO_2 emission – promote environmental quality.

Scholars and researchers have provided extensive literature for different countries and regions regarding the role of green finance in environmental degradation or environmental sustainability. Specifically, (Meo & Abd Karim, 2021) investigated the role of green finance in CO_2 emission in the top-10 green finance supporting economies by employing a quantile on quantile regression approach. The estimated results reveal that green finance negatively and significantly affects CO_2 emissions in the region. Yet, the authors argued that variation across quantiles is primarily due to countries' market and economic conditions. Whereas (Hafner et al., 2020) empirically reveal that short-termism and policy uncertainty are the primary barriers to green finance investment. Concerning the role of green finance in environmental regulations, (Falcone, 2020) argued that the transformation to sustainable development is still seen as having a high level of complexity and uncertainty, particularly in terms of establishing the necessary investment projects. In this sense, green finance could play a critical role in speeding up this transformation and ensuring a fair playing field among the conventional and green economies. Specifically, (Muganyi et al., 2021) argued that green finance helps reduce industrial gas emissions in China, while the development of fintech enhances environmental protection investments. In contrast, (Cong et al., 2020) analyzed the role of green finance and carbon cap-and-trade schemes in medium and high emission manufacturers. The results asserted that green finance enhances the negative effect of cap-and-trade on high CO_2 emission manufacturers and vice versa for low to medium CO_2 emission manufacturers. Besides, (Cui et al., 2020) unveil that green finance integrity significantly leads toward sustainable development and cleaner production. However, the authors argued that strengthening government regulations, reducing the green finance production cost of enterprises, institutions, government supervision, and increasing pollution compensation for consumers could play a critical role in mediating green finance's role in sustainable development. Moreover, (Nawaz et al., 2021) asserted that renewable energy consumption, FDI, inflation, CO_2, and research and development significantly promote green finance and climate change mitigation in N-11 countries.

(Naqvi et al., 2021) analyzed a dataset of 2339 funds for 27 emerging markets and revealed that conventional energy funds outperformed green energy funds. These findings point to barriers for investors who choose to go green. However, during the Covid-19 pandemic, the effectiveness of renewable funds deteriorated, emphasizing the extra investment burden. In contrast, used monthly data over the period 2011-2019 for BRICS economies and asserted that green funds outperform brown and black funds in terms of risk-adjusted-performance. Also, the study argued that there is a strong volatility timing for green finance and having a substantial role in the promotion of carbon-neutral investments. In addition, (Umar et al., 2021a) investigate the role of green finance in the assets-caron nexus. The study examines 19 EU member states throughout 2011-2020 and revealed that green loans help banks enhance their asset quality, attributable to carbon-neutral obligors' low cash flow volatility. On the other hand, countries with the resource curse significantly increase the probability of default risk in the banking and financial sector, which also harms green loans and investments (Umar et al., 2021b).

Nonetheless, green finance is connected to environmental quality. However, after the sudden outbreak of Covid-19, each economic and financial sector is severely affected. In this regard, (Rizvi et al., 2020a) analyzed the performance and investment style of European Union (EU) funds in the Covid-19 pandemic period and revealed that only the social entrepreneurship funds exhibit progressive returns, while other subcategories showed negative returns. While most investment funds have struggled, social entrepreneurship funds have held up well and showed volatility timing, lacking in its most counterparts (Mirza et al. 2020a). Besides, (Yarovaya et al., 2021) imply that during the Covid-19 epidemic, equities funds with better HCE rankings surpassed their counterparts in five EU countries, which can be improved by investing in human capital (Mirza et al., 2020b). In addition, (Yarovaya et al., 2020a) and (Mirza et al., 2022) instigate that relative to non-Islamic equity funds, the Islamic ones are more resilient to Covid-19 pandemic shock, which could be used as a safe haven for equity funds. The recent study of (Rizvi et al., 2020b) investigated the influence of the Covid-19 crisis on the valuation of 5342 non-financial enterprises in ten EU member economies over the period 2010-2019 and found that epidemic is the primary cause of the destruction in shareholders' value. Specifically, the drop in shareholders' values is due to the declination of sales and inclination of equity cost, where the highest loss is accounted for 60% in some sectors during extreme cases. Also, (Yarovaya et al., 2020b) investigated 255 credit institutions in ten EU most affected economies and revealed that asset quality had deteriorated significantly across exposure categories, institutional size, and country profile. The study also reports a significant rise in the likelihood of default and a significant fall in financial adequacy, which is also evident in the recent study of (Mirza et al., 2020c).

Additionally, political risk and economic risk play a vital role in the sustainable development of the country. Numerous studies have empirically analyzed these variables in comparison with determinants of environmental degradation. Specifically, (VU & HUANG, 2020) used ARDL and Granger causality technique in the case of

Vietnam and revealed that political risk and other variables (economic growth, increased electricity consumption, trade liberalization) significantly promote environmental degradation. In the case of low and lower-middle-income economies, (Purcel, 2019) investigated the period of 1990-2015 via employing a panel vector autoregressive model (PVECM). The estimated results illustrate that political stability reduces CO_2 emissions only after reaching the optimum level while environmental degradation surges due to political instability. In the most recent study, (Su, Umar, Kirikkaleli et al., 2021) examined Brazil between 1990-2018 and concluded that economic growth, financial development, and trade openness increase CO_2 emissions. However, a better political environment reduces CO_2 emissions. In addition, Lee and (Chen et al., 2017) empirically investigate 123 economies over the period 1992-2016 and conclude that political risk promotes environmental degradation. Also, the influence of political risk is greater than that of economic risk and financial risk. Moreover, (Anser et al., 2021) investigated BRICS economies and empirically asserted that geopolitical risk significantly promotes environmental degradation by increasing CO_2 emission in the region. Although economic risk and political risk is playing a vital role in environmental quality. However, these risks are also detrimental for income at individual as well as aggregate level. Therefore, (Umar et al., 2021c) suggested that bitcoin could be used as a safe haven asset to counter political and economic uncertainties in the US.

Concerning economic policy uncertainty, (Adams et al., 2020) reveal that economic policy uncertainty, economic growth, and energy consumption positively affect CO_2 emission. Also, the study found unidirectional causality from CO_2 emission to economic policy, while bidirectional causality between economic growth, energy consumption, and CO_2 emission. Concerning the causal association between economic policy uncertainty and CO_2 emission, (Pirgaip & Dinçergök, 2020) investigated G7 economies between 1998 and 2018. The estimated result validated unidirectional causality from economic policy uncertainty to CO_2 in the US, vice versa in Italy, and bidirectional causality for other countries under consideration. In contrast, (Abbasi & Adedoyin, 2021) investigated China over the period 1970-2018 via the dynamic ARDL approach and concluded that economic policy uncertainty does not significantly influence CO_2 emission. On the other hand, (Syed & Bouri, 2021) empirically asserted that economic policy uncertainty significantly increases CO_2 emissions in the short run while promoting long-term environmental sustainability. On the contrary, (Anser et al., 2021) investigated the top ten carbon-emitting economies from 1990 to 2015 and concluded that economic policy uncertainty enhances environmental quality by reducing CO_2 emission in both the short and long run. Although the literature has been extensive regarding political risk, economic risk, and CO_2 emission, still the findings are mixed and contradictory. Therefore, more research work is necessary to instigate the real impact of both political and economic risks on environmental quality.

3. Data and methodology

3.1. Data specification

Based on the objectives of this research, the current study used a total of five variables, where the main variable here is carbon dioxide (CO_2) emission, which indicates

Table 1. Variable specification and data sources.

Variable	Description	Data source
CO_2	Emissions are created by burning fossil fuels and manufacturing cement; they include carbon dioxide produced by solid, liquid, and gas fuel use and gas combustion and measured in kiloton (kt).	https://databank.worldbank.org/source/world-development-indicators#advancedDownloadOptions
GF	The goal of green finance is to enhance the amount of money flowing into sustainable development objectives from the governmental, private, and non-profit sectors via banking, microcredit, insurance, and investment.	http://www.epschinadata.com/auth/platform.html?-sid=E8185F1E89C9A2-466BB8430C45BF4A3E_ipv433008563
GDP	Gross domestic product is the total monetary or market worth of all completed products and services produced inside a country's boundaries in a certain time period is known.	https://databank.worldbank.org/source/world-development-indicators#advancedDownloadOptions
PR	Political risk refers to the possibility that an investment's returns will deteriorate due to a country's political changes or instability. A change in government, legislative bodies, other foreign policy makers, or military power might all cause instability that affects investment returns.	https://www.prsgroup.com/explore-our-products/international-country-risk-guide/
ER	Economic risk refers to the possibility that macroeconomic conditions (the state of the entire economy) will impact investment or a company's local or international prospects.	https://www.prsgroup.com/explore-our-products/international-country-risk-guide/

Source: Completed by the authors.

environmental quality. A higher level of CO2 emissions indicates environmental degradation, while the no or lower level of CO2 emission designates better environmental quality. Additionally, the main independent variable used in this study is green finance (GF). GF variable holds importance because it encourages and supports financial instruments' flow and related services toward the formation and implementation of sustainable business models, investment, trade, economic, environmental, and social initiatives, and regulations. Hence, the GF is influential in economic activities and plays a role in the country's environmental performance.

Besides, GF is the flow of financial instruments, which could highly depend on the country's economic conditions. Therefore, to present the country's economic condition, gross domestic product (GDP) could be an efficient determinant, which measures the size and health of a country in a specific period of time.[1] This measure of an economy's health considers aggregate production, consumption, investment, and other macroeconomic variables. Hence, the higher level of GDP could enhance economic activities, which would relatively consume more energy and natural resources – may affect the environment. Moreover, environmental conditions could also be influenced by political risks (PR) and economic risks (ER), which could provide stringent or flexible policies and investments that could strongly influence a country's economic conditions. Therefore, investigating both these variables holds importance in environmental economics. For all these stated variables, this study used the most updated data set for China while covering the period from 1990-2020. Since 1990, technology has been rapidly developing in emerging as well as developed nations. This advancement in technology speeds up production and other economic activities to achieve higher economic objectives. However, with the higher industrial growth, a country like China became the leading energy importer and carbon emitter globally – majorly contributing to climate change and global warming. Therefore, China focused on the development of green finance to overcome this hazardous issue of global warming and climate change. Hence, it is important to investigate this connection from the last three decades. Additionally, the variables specifications, units, and data sources are provided in Table 1.

3.2. Estimation strategy

The current study employed a wavelet approach to analyze the correlation of various time-varying strategies such as green finance, economic growth, political risk, and economic risk on environmental conditions of China. Nonetheless, time-varying estimating approaches are available, such as recursive cointegration or rolling-sample spillover index methodology proposed by (Diebold & Yilmaz, 2009). However, the wavelet approach is yet considered more robust by providing a better representation of short-run and long-run trends and causalities of time series. Compared to other short and long-run traditional approaches such as cointegration and error correction, the wavelet approach decomposes a time series into a precise time scale. Besides, as per (Umar et al., 2020b), the wavelet analysis allows the difference in data and essential information's validation, which could be lost in other time-varying approaches. That is, the wavelet approach indicates how the time series element varies over time. This splits the considered time series into the scale and shifts the mother wavelet time type (Aguiar-Conraria et al., 2008). Additionally, the wavelet transforms – where the wavelet's length autonomously fluctuates over time allows for natural local analysis of time variables. However, this analysis can be compressed into a short wavelet component to analyze higher-frequency fluctuations, and it can also be expanded into a long wavelet function to estimate the pattern of lower-frequency fluctuations. In order to record fast changes, the short wavelet functions are adequate (narrow windows), whereas the expanded function could be utilized for the isolation of slow and steady variations (wide windows). Furthermore, the wavelet approach provides efficient estimation by transforming the non-stationary time series issues into empirical proofs, which other approaches are restricted to estimate (Sifuzzaman et al., 2009). These aforementioned are the advantages of the wavelet approach over other time-varying approaches in an empirical investigation. Since the wavelet approach, as discussed earlier, efficiently decomposes time variables such as CO_2 emission, green finance, economic growth, political risk, and economic risk throughout the study period. This method is more reliable by considering the non-stationary properties of the said variables. Moreover, to achieve the study objective (mentioned in Section-1), the wavelet coherence is an efficient approach that considers the combined time-frequency domain of CO_2 emission – economic growth, CO_2 emission – green finance, CO_2 emission – political risk, and CO_2 emission – economic risk. Hence, based on such advantages, the current study utilized a wavelet approach including wavelet power spectrum and the wavelet coherence to investigate vulnerabilities or volatilities and causal association of discussed variables. A brief discussion of the adopted methodology and results estimation is provided in the following sections.

3.2.1. Continuous wavelet

The current study employed a novel wavelet approach, in which the wavelet coherence approach determines time-frequency domain causalities for all the variables under consideration in both the short-run and long-run. Generally, the wavelet is an integral squared function with real value and mean equal to zero, and symbolized as ψ, which is presented as follows:

$$\psi_{\mathcal{T},\ \mathcal{S}}(t) = \ \mathcal{S}^{-1/2}\ \psi\left(\frac{t\ -\ \mathcal{T}}{\mathcal{S}}\right) \tag{1}$$

Where in the above Eq. (1), $\mathcal{S}^{-1/2}$ is normalized constant and reveals the unit variance held by wavelet. Besides, the wavelet consists of two parameters, namely: location/time ($\mathcal{T}$) and frequency ($\mathcal{S}$). Both time and frequency parameters are critical for determining the precise wavelet position in time, which is largely attributable to wavelet fluctuations, and regulating distended frequency changes, respectively.

The ψ function will waggle over the *t-axis* and perform like a wave. Here, the specific type of wavelet used basically belongs to the Morlet wavelet family proposed by (Goupillaud et al., 1984), which could be presented as Eq. (2) below:

$$\psi(t) = \ \pi^{-\frac{1}{4}}\frac{1}{e^{i\omega_0 t}}e^{-\frac{1}{2}t^2} \tag{2}$$

Where in the above Eq. (2), $\pi^{-\frac{1}{4}}$ is the normalization factor displaying the unit energy of wavelet, and $e^{-\frac{1}{2}t^2}$ indicates Gaussian envelope with one unit of standard deviation. Moreover, $e^{i\omega_0 t}$ designates complex sinusoid. Additionally, the wavelet used in this case estimates only finite time series data [p(t) = 1, 2, …, T]. According to the uncertainty principle of Heisenberg, the distinction between time and scale localization is ambiguous. Hence, following (Rua & Nunes, 2009), the Morlet wavelet $w_0 = 6$ is efficient for the central frequency due to its efficiency in balancing the time and scale localization.

3.2.2. Continuous wavelet transform

The continuous wavelet transforms $W_p(\mathcal{T},\ \mathcal{S})$ allows us to compute the temporal variation of the frequency of time series. The continuous wavelet transform could be expressed in the equation as follows:

$$W_p(\mathcal{T},\ \mathcal{S}) = \ \int_{-\infty}^{\infty} p(t).\mathcal{S}^{-1/2}\psi^*\left(\overline{\frac{t\ -\ \mathcal{T}}{\mathcal{S}}}\right)dt \tag{3}$$

Where in the above Eq. (3), the '*' represents complex conjugates, while the $\mathcal{S}$ identifies whether the wavelet distinguishes components of the $p(t)$ at lower or higher scale, which could be plausible after satisfying the acceptability condition. Moreover, if the scale is found higher, this indicates lower wavelets or fluctuation, while the lower scale indicates higher wavelet fluctuation. It is relevant to use the wavelet power spectrum (WPS) in this case because this approach provides more information and amplitude of a specific time series. The WPS worked on the following squared form as given below:

$$WPS_p(\mathcal{T}, \mathcal{S}) = \left|W_p(\mathcal{T}, \mathcal{S})\right|^2 \tag{4}$$

3.2.3. Wavelet coherence

Once the wavelet power spectrum is evaluated, this study utilized the wavelet coherence technique. Nonetheless, there are many similarities and differences of wavelet coherence to other existing methodologies. This approach is different from these other methods by allowing for the correlation identification among two-time variables, i.e., p(t) and q(t), in a combined time-frequency domain. The cross-wavelet transform of both the time series is presented in equation form as follows:

$$W_{pq}(\mathcal{T}, \mathcal{S}) = W_p(\mathcal{T}, \mathcal{S})\overline{W_q(\mathcal{T}, \mathcal{S})} \tag{5}$$

Where in the above Eq. (5), $W_p(\mathcal{T}, \mathcal{S})$ and $W_q(\mathcal{T}, \mathcal{S})$ represents the transformation of cross-wavelet for p(t) and q(t), respectively. Moreover, the bar indicates complex conjugates. While the left-hand side W_{pq} (cross-wavelet transform) identifies the covariance of both time series at a specific scale. The wavelet power spectrum reflects covariance contribution in the time-frequency space, whereas cross-wavelet power captures contribution to the series' variance at each time scale.

As mentioned earlier, the wavelet coherence records the frequency co-movement of two-time series, p(t) and q(t). (Torrence & Compo, 1998), on the other hand, offered the squared version of wavelet coherence, which could also be stated as follows:

$$R^2(\mathcal{T}, \mathcal{S}) = \frac{\left|D\left(\mathcal{S}^{-1}W_{pq}(\mathcal{T}, \mathcal{S})\right)\right|^2}{D\left(\mathcal{S}^{-1}\left|W_p(\mathcal{T}, \mathcal{S})\right|^2\right)D\left(\mathcal{S}^{-1}\left|W_q(\mathcal{T}, \mathcal{S})\right|^2\right)} \tag{6}$$

From Eq. (6), D is the smoothing process of time. Additionally, the value of the above-mentioned equation exists between 0 and 1, i.e., $0 \leq R^2(\mathcal{T}, \mathcal{S}) \leq 1$. However, it is noteworthy that when the value of $R^2(\mathcal{T}, \mathcal{S})$ is heading towards zero, indicating no correlation between p(t) and q(t). Conversely, if $R^2(\mathcal{T}, \mathcal{S})$ value is moving towards 1, and this illustrates a strong correlation between p(t) and q(t). In a wavelet coherence, the correlation could be differentiated by colors ranging from blue to yellow-red. Specifically, blue indicates no or weak correlation, while yellow-red indicates a strong correlation between p(t) and q(t).

3.2.4. Phase

Concerning the analysis procedure of $R^2(\mathcal{T}, \mathcal{S})$, there is no clear distinction that reveals whether the correlation exists between p(t) and q(t) is positive and/or negative. In this regard, the current study used the wavelet coherence phase difference to investigate the positive and/or negative correlation along with the lag-lead association between the two time series in the rime-frequency domain. Hence, following the study of (Torrence & Webster, 1999), the wavelet coherence phase difference could be estimated via the following equation:

$$\phi_{pq}(\mathcal{T},\ \mathcal{S}) = \tan^{-1}\left(\frac{\mathrm{L}\left\{D\left(\mathcal{S}^{-1}W_{pq}(\mathcal{T},\ \mathcal{S})\right)\right\}}{O\left\{D\left(\mathcal{S}^{-1}W_{pq}(\mathcal{T},\ \mathcal{S})\right)\right\}}\right) \tag{7}$$

In the above Eq. (7), L and O represent the real part and imaginary part of the smooth power spectrum, respectively. Furthermore, $\phi_{pq}(\mathcal{T},\ \mathcal{S})$ Estimates a two-dimensional graph, which illustrates the wavelet coherence's empirical findings.

Once the results are obtained via the wavelet approach, the empirical findings could be interpreted as follows. In the wavelet coherence graphical depiction, the horizontal axis represents time, while the vertical axis represents frequencies. A lower frequency indicates a larger size. Wavelet coherence may be used to find two-time series that co-vary in the time-frequency domain. Furthermore, yellow-red denotes a strong link between series, whereas blue denotes a lesser link between time variables under consideration. The cooler places away from the key region(s) suggest time and frequency since the series has no relationship. Additionally, arrows in the wavelet graphical presentations reflect the lag and lead phase relationship between the studied variables. The zero phase shift depicts the co-movement of two-time variables at a certain scale. Besides, when the arrows go to the right, the time series are in phase or have a positive correlation, but when the arrows travel to the left, the time series are out of phase or have a negative correlation. When two series are in phase, both variables move in the same direction, but when they are antiphase, they flow in the opposite direction. Furthermore, on a wavelet coherence schematic graph, an arrow traveling up, left-up, or right-down shows that the first variable causes the second variable. Conversely, the second variable will cause the first variable when the arrows are pointing down, left-down, right up.

4. Results and discussion

There are numerous economic and non-economic variables, which may hold non-stationary properties. However, most of the estimating approaches are not allowing for the empirical analysis of non-stationary series. Besides, these non-stationary series may hold dominant periodic signals with changing frequency and amplitude over time, which could be tackled by the wavelet power spectrum. This approach captures the fluctuating patterns in CO2 emission, green finance, economic growth, political risk, and economic risk over the period 1990-2020. Also, as per the study's objectives, these variables' time-frequency dependence could instigate a few questions: (i) whether time-frequency dependence is valid for the above-mentioned variables? (ii) If valid, what is the causal direction between these variables? (iii) Whether the association exists in a particular time (i.e., short-run, long-run) or across the selected time period. In order to answer these questions, the current study adopted the wavelet coherence approach for empirical investigation of China. Hence, both approaches of the wavelet method are adopted in this study.

4.1. Results and discussion of the wavelet power spectrum

With reference to Figures 1–5, the graphical display of wavelet power spectrum indicates the cone of influence, which further specifies an edge. However, below that edge, the wavelet power spectrum provides insignificant results – cannot be interpreted. Concerning the wavelet power spectrum empirical results, the graphical display of CO_2 emission and GDP shows a clear blue color in the influential cone with no contour. This indicates that both of these time variables do not possess any vulnerability in the selected period. However, the contour has been found in the pre and post influential periods, which could not be interpreted. Hence, it is concluded that these two variables have no vulnerabilities throughout 1990-2020. On the other hand, green finance showed significant vulnerabilities. Specifically, green finance was found vulnerable from 2005 to 2014. Although, this vulnerability is weak, as the blue-green color mentioned. Still, the frequency is higher in the earlier period, i.e., 2005-2009 with frequency from 5 to 8, and the scale is higher lately, i.e., 2010-2014, with frequency from 0.5 to 2.5. This indicates that the vulnerability of green finance is detected in both the short-run and long run. Concerning the higher scale of green finance after 2009 reveals that this vulnerability may occur due to the global financial crisis, which disturbed most economical and financial activities worldwide. As one of the largest exporting economies, China could also face the crisis of global financial crisis (2009), which creates uncertainty in the green finance market.

Moreover, political risk and economic risk also indicate lower to no vulnerabilities throughout the selected time period, but relatively greater than vulnerabilities in CO_2 emission and GDP, while lower than the vulnerabilities in green finance. Specifically, political risk indicates volatilities but insignificant, as the contour exists outside the influential cone. Therefore, it is concluded that political risk holds from lower or no volatility

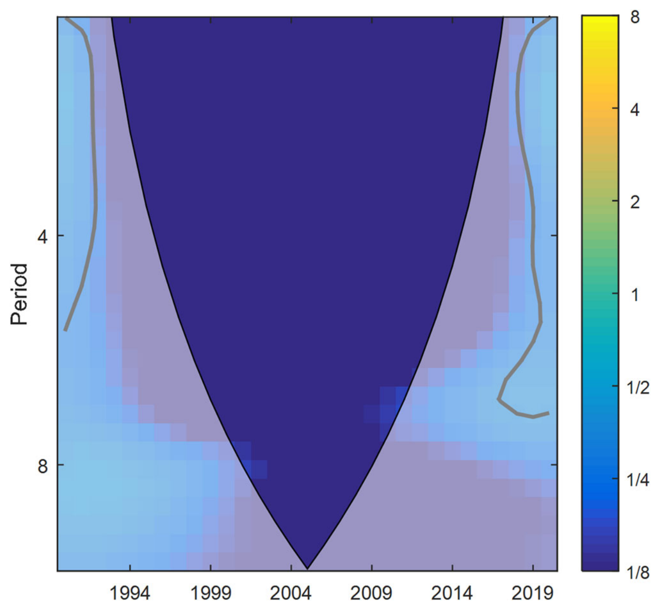

Figure 1. Wavelet power spectrum for CO_2 emission.
Source: Completed by the authors.

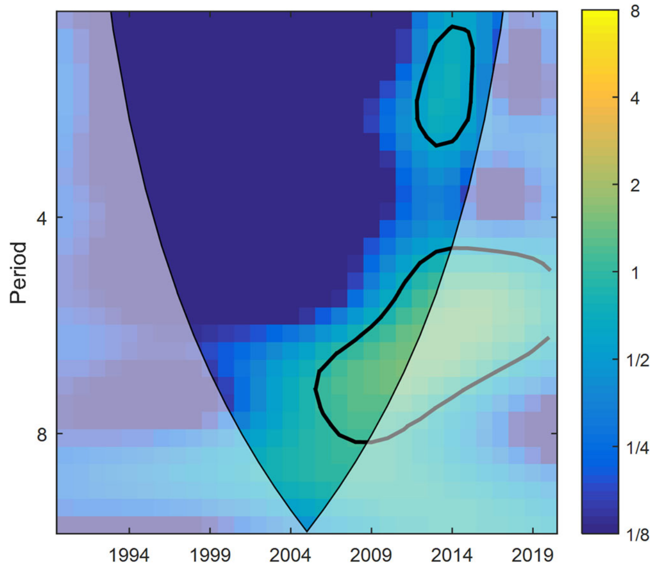

Figure 2. Wavelet power spectrum for green finance.
Source: Completed by the authors.

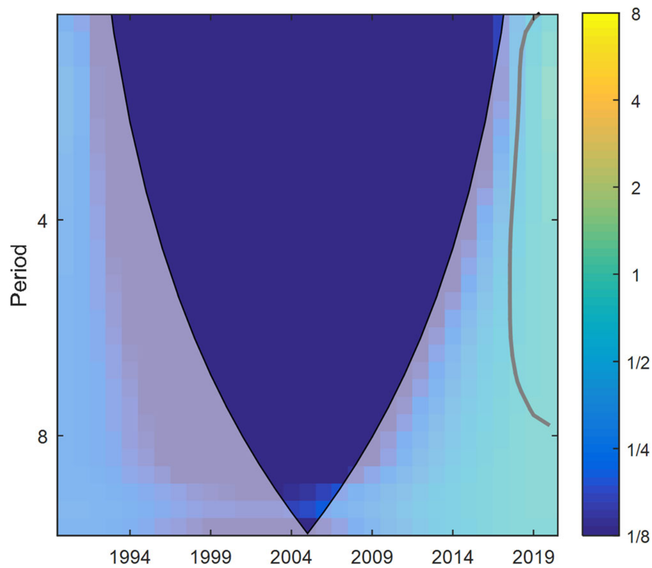

Figure 3. Wavelet power spectrum for GDP.
Source: Completed by the authors.

throughout the significant region in the selected period of time. On the other hand, economic risk showed a little higher vulnerability than the political risk in China. Particularly, a significant vulnerability in economic risk is found during the period from 1995 to 1997. Besides, another region also displays a blue-green color, which depicts volatility in economic risk. Still, the region is insignificant. As the graphical display reveals only significant volatility in the 1995-1997 period. Therefore, it could be stated that this period holds global and regional crises such as the 1990s Gulf war and the 1997 Asian

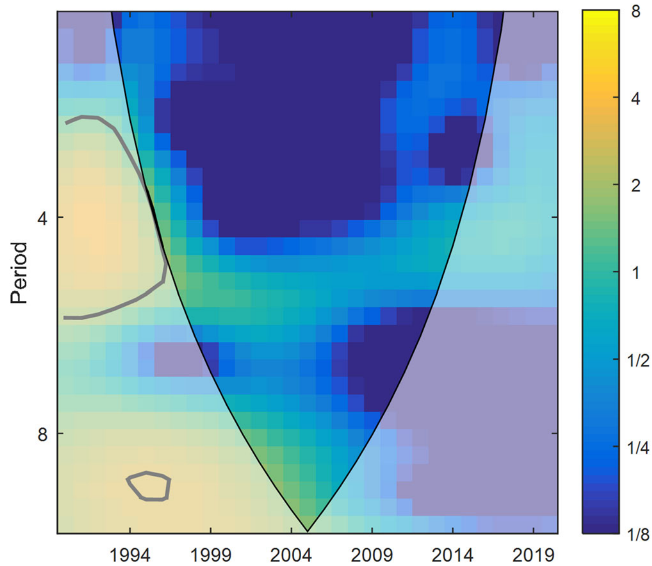

Figure 4. Wavelet power spectrum for political risk.
Source: Completed by the authors.

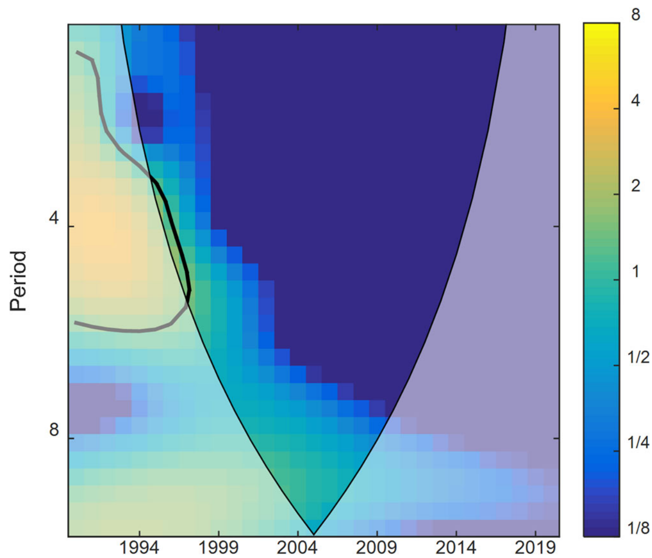

Figure 5. Wavelet power spectrum for ER.
Source: Completed by the authors.

financial crisis. As the world is a globalized village, any event or crisis in one country or region significantly influences other countries or regions. Hence, these two events could be the main reason for economic risk instability in China.

4.2. Results and discussion of the wavelet coherence

With reference to Figures 6–9, the horizontal line indicates time, and the vertical line represents frequency in the wavelet coherence graphical display, which analyze the

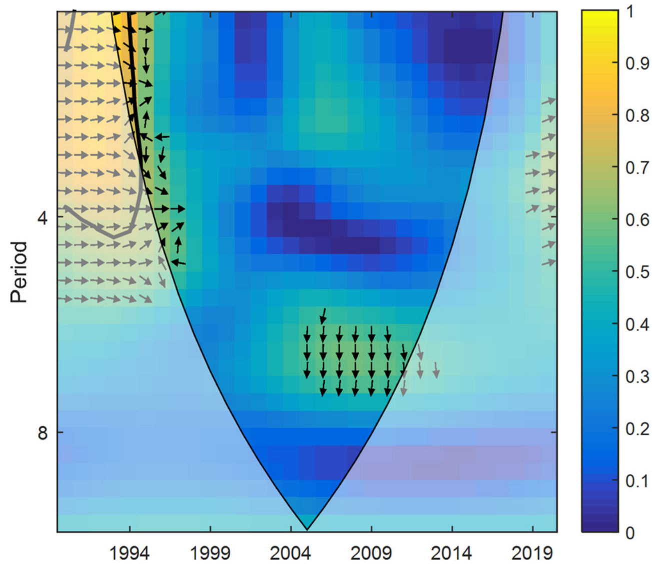

Figure 6. Wavelet coherence between CO_2 emission and green finance.
Source: Completed by the authors.

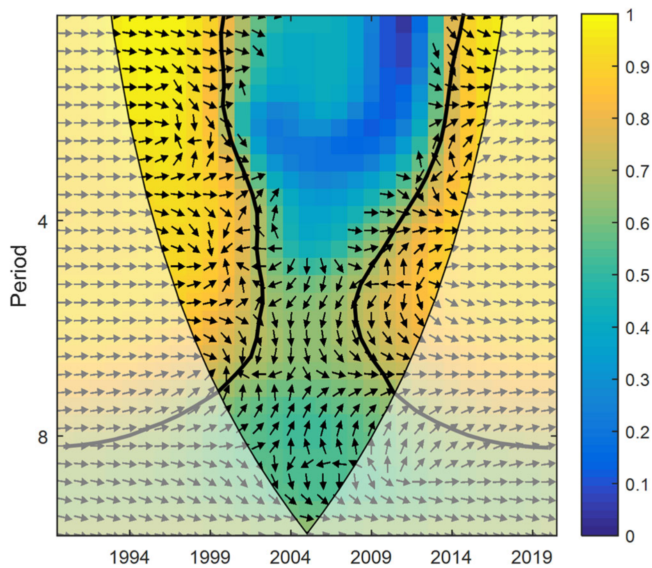

Figure 7. Wavelet coherence between CO_2 Emission and GDP.
Source: Completed by the authors.

short-run and long-run causal linkage between green finance, economic growth, political risk, economic risk, and CO_2 emission in China over the period 1990-2020. Similar to the wavelet power spectrum, the wavelet coherence graph identifies the causal influence by colors, where the blue (colder) color depicts weaker or no inter-relationship, while red (hot) color strong inter-relationship between the variables under consideration (Kirikkaleli, 2020). Additionally, the arrow in these figures depicts causal linkage: when traveling to the right (left) – the variables are in phase

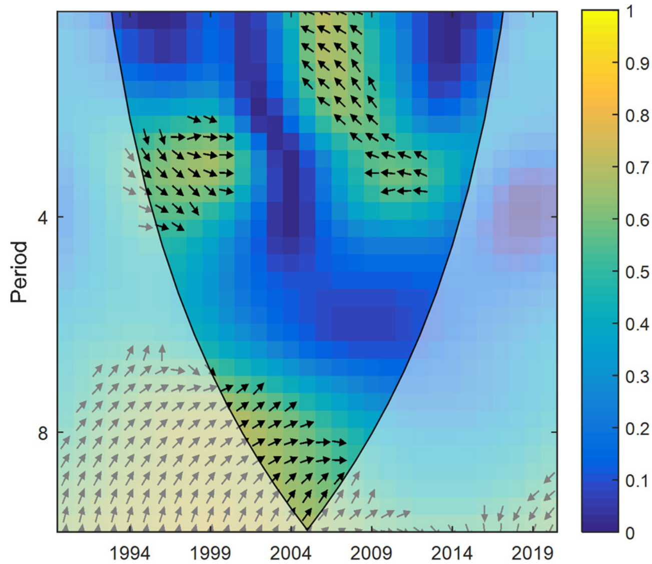

Figure 8. Wavelet coherence between CO_2 emission and political risk.
Source: Completed by the authors.

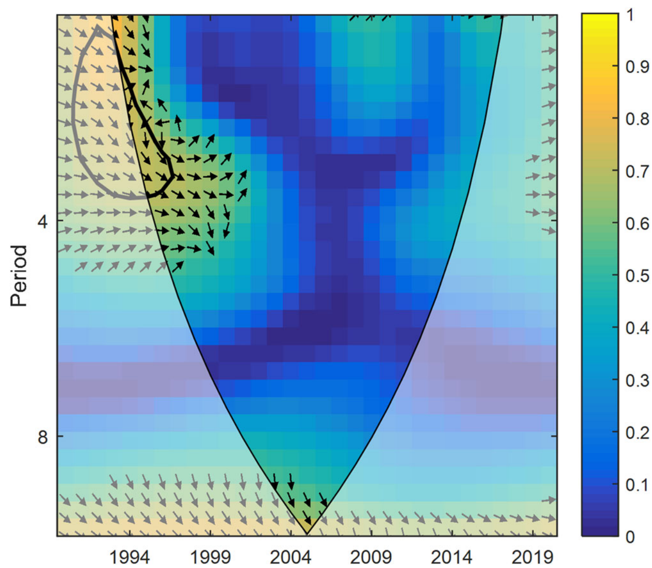

Figure 9. Wavelet coherence between Co_2 emission and economic risk.
Source: Completed by the authors.

(antiphase) – moving in the same (opposite) direction. Moreover, the first variable is leading when the arrows are pointing up, left-up, or right-down. While the arrows are traveling down, left-down, or right-up – the second variable is leading. This study's empirical findings of wavelet coherence could provide critical policy insights for policymakers, researchers, and scholars.

With reference to Figure 6, the graphs represent wavelet coherence for CO_2 and green finance. Regarding the association of these two variables, there is only one significant region reported in the graphical display, where the inter-relation between these two variables exists. Specifically, the significant region indicates a correlation between the two-time series from 1993 to 1995. The causal connection is valid due to the fact that China is an emerging economy with rapid economic growth since China reforms. However, these reforms in the 1970s paid great attention to economic growth than environmental sustainability. However, in the 1990s, the global climate change institutions raised their voice for environmental mitigation, which forced China to limit CO_2 emission. This speeds up the intentions of the investors and policymakers to enhance green finance and other environmental sustainability measures. Additionally, the arrows indicate a causal association between CO_2 emission and green finance in the mentioned significant region. That is, the arrows are found heading in the right-down and right-up direction. This reveals that a bidirectional causal association exists between CO_2 and green finance but only in the short run. Still, the causal influence of CO_2 emission is higher in scale, which is reported from 0 to 1.5. While the causal influence of green finance is higher in frequency, which is reported from 1.5 to 2.5. Besides, the right-headed arrows indicate that the relationship is in phase. These empirical findings are in line with the study (Cong et al., 2020), which empirically demonstrated that green finance enhances CO_2 emission in the lower and medium CO_2 emission manufacturers. While the results are contrary to (Cui et al., 2020), (Meo & Abd Karim, 2021), and (Muganyi et al., 2021). These studies demonstrate the positive influence of green finance on CO_2 emission. The main reason for the positive impact of green finance is that China is an emerging economy, where policymakers pay more attention to economic development rather than environmental sustainability.

Regarding Figure 7, the graphical display depicts the inter-relationship between CO2 emission and GDP, which designates a greater inter-relationship between these variables. Specifically, there are two significant regions found where the CO_2 emission and GDP are inter-related, i.e., 1993-2003 and 2008-2016. These regions showed mixed causality between CO_2 emission and GDP. The arrows in the first period (1993-2003) are rightly headed, indicating that both of these variables are positively correlated and moving on the same path. Similar findings have been presented by earlier studies such as (Bosah et al., 2021; Malik et al., 2020; Song, 2021; Yang et al., 2021; Zhang et al., 2021). These studies revealed that economic growth enhances production and economic activities, which use energy and natural resources that causes environmental degradation by emitting CO_2 emission. While in the second period (2008-2016), the arrows were found traveling to the right and left, indicating that the relationship is positive and negative. While the negative impact of economic growth is only possible by the structural transition of the industrial sector via increasing the research and development investment (Dong et al., 2020; Wang & Zhang, 2020). Besides, in both the significant regions, the arrows are found traveling towards right-up, right down, left-up, and left-down, which depicts a bidirectional causal association of economic growth and CO_2 emission. The estimated results are identical to the findings of (Malik et al., 2020). The study identifies a bidirectional causal association between CO_2 emission and economic growth for Pakistan. Moreover, the empirical results of the current study validate the long-run causal association between CO_2 emission and economic growth.

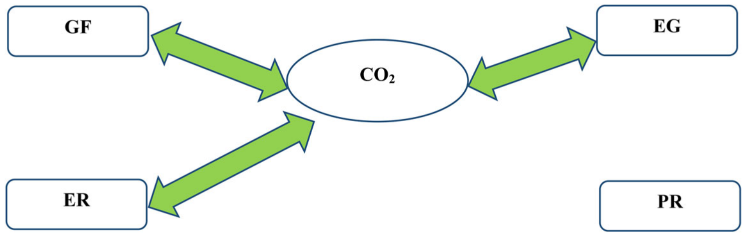

Figure 10. Graphical representation of empirical findings.
Source: Completed by the authors.

With reference to Figures 8 and 9, the graphical display reveals a causal association of CO_2 and political risk and CO_2 emission and economic risk, respectively. Firstly, the wavelet coherence of CO_2 and political risk indicates three regions where the causal association could exist between them. However, these regions are found insignificant due to the absence of contour, which depicts a significant inter-relationship of the time series at the 5% level. On the other hand, a significant causal association is found between CO_2 emission and economic risk. Specifically, this causal association is found only in the short run, which is valid only for the period from 1994 to 1997. The significant region indicates that the arrows are traveling to right down and left down. This illustrates the bidirectional causal association between CO_2 emission and economic risk. Besides, the causal impact of CO_2 emission is more stronger than the influence of economic risk. The empirical findings are in line with the earlier studies of (Adams et al., 2020) and (Pirgaip & Dinçergök, 2020), which identified the causal linkage from CO_2 emission to economic risk and from economic risk to CO_2 emission, respectively. This causal association illustrates that both variables play an important role in any policy change in each variable (Figure 10).

5. Conclusion and policy implications

This study investigated the causal association of green finance, economic growth, political risk, and economic risk with the environmental quality captured by the CO_2 emissions in the case of China. The study used the extended dataset available, covering the period from 1990 to 2020. Despite the fact that there are many time-varying methodologies available, this study used the wavelet technique, focusing on the wavelet power spectrum and wavelet coherence. This approach considers two-time variables in a combined time-frequency domain and provides both short-run and long-run estimates at different frequencies and periods. The empirical findings of the wavelet power spectrum demonstrate that the variables are less vulnerable in the study period. Particularly, green finance, political risk, and economic risk are found vulnerable. However, the vulnerability in green finance is found in both the short-run and long-run, where the short-run vulnerability is found at a higher scale. Besides, the economic risk is found vulnerable only in the short run. Nonetheless, many factors could influence these variables and cause volatility. Still, the significant region is found in the era of the 1990s Gulf war, the Asian financial crisis (1997), the energy price hike (2004), and the global financial crisis (2009). Hence, it could be assumed that these global and regional events played a significant role in the volatility of green finance and economic risk. On the other hand, CO_2 emission, and economic growth are found stable across the selected period in China.

Regarding the empirical findings of wavelet coherence, the graphical display reveals a significant causal association between the study variables. Specifically, it is noted that there is a bidirectional causal nexus between green finance and CO_2 emission. However, the causal influence of CO_2 emission is higher in scale, and the causal influence of green finance is higher in frequency. Besides, the nexus of green finance and CO_2 emission is in phase, which indicates that as the CO_2 emissions increase, the green finance investment is also increasing to tackle its negative effect. The wavelet coherence also showed that there is a bidirectional causal association between CO_2 emission and economic growth in the long run. This further demonstrates the existence of the environmental Kuznets curve in China, revealing that economic growth increases CO2 emission in the initial stage while reducing CO_2 emission once the threshold level of income is achieved. China started the transition to environmentally friendly technologies that promote environmentally friendly production and energy-efficient machinery, which leads to environmental sustainability. In addition, there is a bidirectional causal association between CO_2 emission and economic risk, but only in the short run, where the causal influence of CO_2 emission is stronger on the economic risk. Moreover, there is no significant causal nexus identified between CO_2 emission and political risk.

Based on the empirical findings, this study recommends that policies regarding green finance must be revised and strengthened as presently there is no significant contribution of green finance in environmental sustainability. However, increasing green finance investment improves innovative ability and green economic transformation, which assists people in addressing climate change, ecological crises, and energy security issues. Therefore, revised and improved policies regarding enhancement in green finance investment could reduce CO_2 emission in the region. Secondly, empirics show that higher economic growth leads to a reduction of CO_2 emission in the region. Therefore, policies must be strengthened regarding implementing environmentally friendly production and consumption to combat CO_2 emissions in the region. Also, policies must consider transforming to renewable energy resources as green investment and economic growth are rapidly increasing in China. This will help the country to achieve carbon neutrality in the long run. Lastly, political risk and economic risk could be critical for environmental quality in China. Therefore, both political and economic conditions must be minimized, which would lower the risk tendency, encourage green investment and green loans, enhance economic activities and further contribute to environmental sustainability by enhancing investment in innovative technologies.

Since this study provides empirical evidence of the causal correlation between environmental degradation and other economic and non-economic factors in China. Still, this study is limited as the CO_2 emission is not a comprehensive measure of environmental quality. Instead, the future researcher can extend this study by considering greenhouse gas emissions and ecological footprints. Moreover, this study provides only the causal linkage of CO_2 emission with green finance, economic growth, political and economic risk. However, there are other substantial factors such as financial development, financial inclusion, trade, globalization, human capital, and urbanization, which could be significant determinants of environmental quality in China. Therefore, future studies should also consider these particular indicators for empirical examination. Lastly, this study used only the data for the last 31 years; however, this study can be extended by using an enlarged dataset to provide a comprehensive association of the said variables. Lastly, other econometric approaches such as quantile regression, ARDL, GMM, and OLS are encouraged to utilize for the specific influence of each explanatory variable on CO_2 emission.

Note

1. https://www.bankofengland.co.uk/knowledgebank/what-is-gdp

Disclosure statement

No potential conflict of interest was reported by the authors.

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