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The effect of green finance and unemployment rate on carbon emissions in china

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China's economy has developed rapidly since the reform and opening up, but under the long-term traditional extensive development model, energy consumption is excessive and carbon emissions rank first in the world. Therefore, how to reduce carbon emissions is a current hot issue in China. Although many scholars have found that green finance is the basic driving force to promote carbon emission reduction, its role path is diverse, and it still needs to be explored in width and depth. Especially in the green transformation stage of the economy, the potential unemployment risk is also a matter of concern. This study selects 30 provincial panel data from the Chinese mainland for the 2004–2019 years to investigate the impact of green finance on carbon emissions from the perspective of unemployment using ordinary least square (OLS), generalized method of moments (GMM), and mediating effect models. In addition, in order to avoid the bias of regression results caused by the cross-section dependence of the data, the feasible generalized least squares (FGLS) and the panel-corrected standard errors (PCSE) models are used for the robust test after correction. The findings show that 1) green finance has a significant inhibitory impact on carbon emissions; 2) green finance has significantly reduced the unemployment rate; 3) carbon emissions increase significantly with increasing the unemployment rate; and 4) there is regional heterogeneity in the effect of green finance on carbon emissions in eastern, central, and western China. Green finance in the eastern and central regions significantly inhibits carbon emissions, especially in the central region, while insignificantly in the western region. 5) According to the OLS and mediating effect regression results, economic growth and environmental regulation play a significant positive role in promoting carbon emissions. This study has theoretical reference significance for accelerating the realization of the dual carbon goal and alleviating phased unemployment.

KEYWORDS

mediating effect, regional heterogeneity, peak carbon emissions, green finance, the unemployment rate

1 Introduction

From the international context, in recent years, global attention to climate change has continued to increase (Anser et al., 2020a; Alharthi et al., 2021; Hua et al., 2022). To reduce global greenhouse gas emissions, countries around the world have carried out a series of measures to deal with climate change (Yang et al., 2021a; Balsalobre-Lorente et al., 2022; Usman et al., 2022). Through unremitting endeavors lately, China has largely accomplished the Millennium Development Goals and became the world's second-biggest economy and the top exporter (Zhao et al., 2020; Irfan et al., 2021a; Koondhar et al., 2021; Zhao et al., 2021). To better cope with climate deterioration and assume the responsibility of great powers, the Chinese government affirms at the 70th United Nations General Assembly and Climate Summit to improve the 2015 Paris Agreement's carbon reduction goals (Abbasi et al., 2022). Specifically, gross carbon emissions will peak in 2030 and achieve carbon neutrality in 2060 (Wu et al., 2020; Ren et al., 2021; Shen et al., 2022). While China affirms that carbon emissions will peak by 2030 is not surprising, the commitment to carbon neutrality is unexpected (Iqbal et al., 2021; Wen et al., 2022). Since China has far less time to achieve carbon neutrality and peak carbon emissions than developed countries, its economy, and energy mix need to adjust to low-carbon and decarbonization depth with unprecedented intensity (Al et al., 2019; Iqbal et al., 2019a; Khan et al., 2021; Rauf et al., 2021), thus facilitating an orderly peaking of carbon emissions across regions, sectors, and industries (Wu H. et al., 2019; Hao et al., 2020). Also, the achievement of carbon neutralization and peak carbon emission goals require a large amount of investment (Tang et al., 2022; Xiang et al., 2022). It is urgent to accelerate the construction of green finance and the national carbon emission trading market, guide the rational allocation of resources, leverage resources to lean toward green and low-carbon projects, and promote green and low-carbon development (Razzaq et al., 2021a; Qiu et al., 2021).

From the domestic environment, green finance is a wide conception (Ahmad et al., 2021; Ali et al., 2021). According to the definition in the Guidance on Building a Green Financial System issued by the Chinese government in 2016, green finance refers to economic activities that support environmental improvement, climate change, and the economical and efficient use of resources, that is, financial services providers for project investment and financing, project operation and risk management in the fields of environmental protection, energy conservation, clean energy, green transportation (Irfan and Ahmad, 2021), and green buildings (Jiang et al., 2020). Green finance not only involves investment and financing support services for various types of green projects such as clean energy and green materials, but also refers to financial services such as green credit, green bonds, green industry investment, green development funds, green insurance, and other financial services that support the transformation of the economy to green development (Taghizadeh-Hesary and Yoshino, 2019; Sun, 2021; Meo and Abd, 2022). As an emerging financial model, green finance provides powerful financial tools to support carbon emission reduction with the continuous enrichment and improvement of its product connotation and business types (Taghizadeh-Hesary and Yoshino, 2019; Hafner et al., 2020; Razzaq et al., 2020). Green finance is not only significant support for green enterprises through providing funds but can also significantly improve energy efficiency and ultimately achieve the vision of "carbon neutralization and peak carbon emissions" (Hou et al., 2019; Iqbal et al., 2019b; Shen et al., 2021). According to relevant calculations, China needs a huge amount of green financial investment of more than 100 billion yuan to achieve the goal of "carbon neutrality and peak carbon emissions". In addition to government funds, most of them need to be market-oriented to guide and encourage social capital through financial system investment and financing (Hao et al., 2021; Razzaq et al., 2021b; Ren et al., 2022b).

Green finance, with green credit, green securities, green assets, and green protection as the principle apparatuses, has grown quickly (Chandio et al., 2021; Tanveer et al., 2021; Fang et al., 2022). The "green capital" has extended its help for green ventures and sped up the green change of energy structure and modern construction (Irfan et al., 2021b). In this process, green finance indirectly affects carbon emissions by affecting the unemployment rate. With the green transformation of China's economy, some traditional polluting industries are bound to face structural upgrading (Zhu et al., 2014; Ren et al., 2022c). However, in the process of transformation from an extensive industry to a high-tech industry, a large number of low-level labor force members, including those in such enterprises, face the risk of unemployment (Sima et al., 2020). In addition, the traditional polluting enterprises are affected by the crowding-out effect in the development process of green finance, and their financing environment is squeezed, which may increase the unemployment rate due to the shortage of funds (Razzaq et al., 2021a; Ren et al., 2022a; Shi et al., 2022). However, green finance can further influence the allocation of resources and urge enterprises to invest more funds to cultivate green, scientific, and technological talents, to reduce the unemployment rate. In addition, green finance will inevitably drive the flow of talents under the influence of the financial spillover effect, to transport the labor force eliminated by traditional polluting enterprises to the green production sector (Dao et al., 2011; Hao et al., 2021). It is also worth noting that green finance would promote the increase of green entrepreneurship projects and create more jobs (Silajdžić et al., 2015). Therefore, in the green transformation stage of the economy, green finance contributes to reducing the unemployment rate and improving the employment rate. Meanwhile, the reduction of the unemployment rate is of great significance to carbon emission reduction (Islam et al., 2021). As mentioned above, green finance provides financial support for the improvement of labor quality

in the process of green transformation of traditional polluting enterprises through resource allocation, thus influencing the unemployment rate (Zhou et al., 2022). In addition, green finance also provides material conditions for the market labor force to flow from polluting enterprises to green production departments. This transfer of the labor force not only reduces the unemployment rate but also promotes the upgrading of industrial structures and green economic transformation, thus influencing carbon emissions (Wang and Li, 2021). Therefore, the decline in the unemployment rate is closely related to the increase in green talent and carbon emissions. However, few scholars currently conduct empirical research on the above issues. So what are the specific impacts of green finance and the unemployment rate on carbon emissions? This study has theoretical and practical significance and puts green finance, unemployment rate, and carbon emissions into a unified research framework for empirical research for the first time, which enriches the current basic research theory of carbon emissions. In addition, this study provides a new research path for carbon emission reduction and speeds up the realization of the dual carbon goal.

The contributions of this study are as follows: Firstly, it investigates the dynamic effect of green finance on carbon emissions, which enriches the existing literature for China to accelerate the realization of the double carbon goal and serves as some reference for developing economies similar to China to achieve their carbon reduction goals. Secondly, compared with previous scholars who studied the impact of green finance on carbon emissions from the perspective of industrial structure and technological innovation, this study examines the impact of green finance on carbon emissions by taking the unemployment rate as a mediating variable, complementing the existing research on green finance and carbon emissions. Finally, this study also conducts a regional heterogeneity in the effects of green finance and unemployment on carbon emissions, which formulate relevant policies depending on local differences in each area.

The structure of this study is organized as follows: Section 2 reviews the literature and research hypothesis; Section 3 gives the methodology and data; Section 4 proceeds with results analysis; and Section 5 summarizes the entire text and made important recommendations.

2 Literature review and research hypothesis

2.1 Green finance and carbon emissions

Financial development is an important indicator affecting carbon emissions (Shahbaz et al., 2013; Acheampong et al., 2020; Shahbaz et al., 2020). Some scholars have found that financial development could promote carbon emissions (Zhang et al., 2020). From the perspectives of the stock market, energy consumption, economic growth, and political system, these scholars use time series, spatial measurement, and other methods to prove that financial development can promote carbon emissions (Iqbal et al., 2020). Zhang et al. (2011) observe that monetary advancement was not just the primary justification for the increment in carbon emissions, yet in addition, different monetary improvement markers diversely affect carbon emissions. Among them, the effect of the financial mediating scale on carbon emissions is more noteworthy than other financial advancement pointers, for example, financial mediating effectiveness, securities exchange scale, and productivity. Adams and Klobodu (2018) added political elements to the investigation and discovered that financial improvement was the key component prompting the expansion of carbon emissions. Shen et al. (2020) support that a created financial system can diminish data deviation and make it more straightforward for organizations to fund. This will help enterprises expand production scale and lead to an increase in carbon emissions. Chen and Zhang (2014) find that the improvement of financial scale and efficiency would significantly improve the level of carbon emissions by using the spatial econometric model. Boutabba (2014) utilizes the time-series information from 1971 to 2008 to concentrate on the connection between carbon emissions, financial development, exchange receptiveness, and energy utilization. It is observed that finance improvement emphatically affected per capita carbon emissions.

However, different researchers argue that green finance has a conspicuous inhibitory impact on carbon emissions. Researchers who support this hypothesis have demonstrated that green finance has a huge inhibitory impact on carbon emissions through spatial panel models. Liu et al. (2015) find that the green credit policy will significantly reduce the production emissions of energy-intensive industries in the short and medium-term through the transmission path of green credit. He (2019) constructed a VAR model by estimating four components: green credit, green conservation, green protection, and green entrepreneurship, and observed that the development of green finance would radically reduce the level of national CO_2 emissions and promote sustainable economic development. Shao and Fang (2021) built an exhaustive record of green finance development through the entropy weight technique, and at this point not considered single factors, for example, green credit, protections, and venture, alone to make the general development of green finance more intuitive. Based on this, the following hypothesis is proposed in this study.

Hypothesis 1. Green finance has a significant inhibitory effect on carbon emissions.

2.2 Green finance and unemployment rate

In the green transformation stage of China's economy, green finance is closely related to employment. Finance could not only

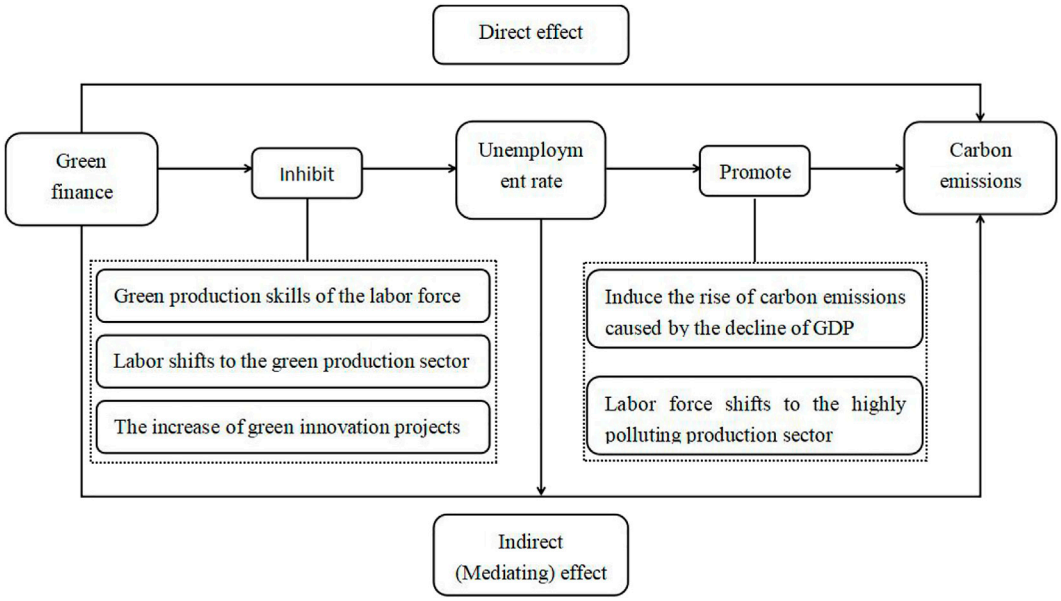

FIGURE 1
Role mechanism diagram.

support the labor–capital investment of enterprises and reduce the risk of unemployment but also promote labor market liquidity through the spillover effect. Since the unemployment rate is an indicator to measure the employment situation of a country, to more intuitively clarify the relationship between green finance and the unemployment rate. Ndubuaku et al. (2021) utilize the ARDL model and annualized time-series information from 1999 to 2019 to research the effect of financial development on the employment rate in Nigeria. The result shows that financial development altogether affects the employment rate. Alkhateeb et al. (2017) used the ARDL cointegration method to investigate the relationship between finance and employment in Saudi Arabia from 1980 to 2015. They found that financial development could assume an important part in economic development and occupation creation. Yang et al. (2015) revealed that the expansion of financial development scale restrained the employment of the primary and secondary industries, however, advanced the employment of the tertiary business and the improvement of financial productivity assumes a positive part in advancing the employment of the tertiary business. Besides, as macro-economic policies such as green finance are limited to green and low-carbon industries, China will create a large number of jobs in the future and promote the transformation of employment into technology-biased and environment-friendly jobs. At the same time, green finance provides financial support for the improvement of labor quality to adapt to the green economy model, which reduces the cost of the unemployment rate and other costs in the process of economic green transformation, and promotes the decline of the unemployment rate (Sun, 2021). In addition, the resource allocation function and spillover effect of green finance will optimize the distribution structure of the labor force in the market, promote the transfer of more labor force from the polluting production sector to the cleaner production sector, reduce the risk of some labor force, and thus hinder the rise of the unemployment rate. Lee (2020) believed that green finance could alleviate employment pressure and provide the impetus for economic development. Khobai et al. (2020) revealed that clean energy investment has improved the employment level in the long term, and has little impact on employment in the short term. He (2017) agreed that clean energy has increased the national employment and the employment of the clean energy industry, but it has a negative impact on the employment of the traditional energy industry. Therefore, the development of green and clean energy played a strong role in promoting green employment, while reducing carbon emissions. Based on this, the following hypothesis is proposed in this study.

Hypothesis 2. Green finance has a significant inhibitory effect on the unemployment rate.

2.3 Unemployment rate and carbon emissions

In the green transformation stage of the economy, it is inevitably accompanied by the transformation from high energy-consuming industries to green and clean energy

industries, and from traditional industries to green and low-carbon industries (Steward, 2012). In this process, the labor force will also undergo structural transfer between industries and industries; that is, the labor force will transfer from traditional industry, high energy, and high consumption industries to green and low-carbon industries. Green finance squeezes financial resources from the polluting production sector to the green production sector, while the labor force will also flow accompanied by financial resources (Wang, 2020). This kind of labor mobility can reduce the impact of economic transformation on the unemployment rate, to reduce it. In addition, green finance also promotes the green transformation of the labor force, cultivates more green talents, and alleviates the impact of economic green reform on employment stability. Meanwhile, a large number of green start-ups have sprouted with the support of green finance, and then more social unemployed people are absorbed by green environmental protection production enterprises, thus improving the reemployment rate of social unemployed people (Henzelmann et al., 2011). Therefore, in the context of "carbon neutralization and peak carbon emissions" goals, part of the reasons for the decline of the unemployment rate have to be attributed to the improvement of green production skills of the labor force, the structural transfer of labor force, and the increase of green innovation projects, which are closely related to carbon emissions. George et al. (2012) pointed out that large-scale development of electricity has a positive effect on reducing unemployment in Nigeria. Bulavskkaya and Reynès (2018) found that the clean energy industry has created thousands of jobs in the Netherlands and effectively promoted economic growth. Mu et al. (2018) confirmed that the improvement of clean energy has positively affected China's business level, especially the scale expansion of wind energy and solar energy industry, which can create employment. To sum up, it can be concluded that green talent training, industrial structure upgrading, and green innovation projects are conducive to improving production efficiency and energy efficiency, to reduce carbon emissions (Cheng et al., 2021).

Conversely, the rising unemployment rate may contribute to rising carbon emissions. Some scholars have conducted extensive research on the relationship between the unemployment rate and economic development, among which the most famous is the alternative relationship between the unemployment rate and GDP proposed by American economist Okun (1962). Besides, by studying a large number of developed and developing economies, Ball (2019) concluded that the coefficient of developing economies is on average lower than that of developed economies, and the effectiveness of Okun Law is different in different economies. Benos and Stavrakoudis (2020) concluded that the dependence between GDP and unemployment by using copula function analysis is only strong in the United States and France. That is, if the unemployment rate becomes higher, the economic level will decline. These research documents show that rising unemployment will lead to a decline in the level of the economy. Other scholars have found that the decline in the economic level will lead to an increase in carbon emissions. According to Wang et al. (2022c), when the level of GDP per capita is within a certain range, if the economic level decreases, to develop the economy rapidly, the government will take measures to stimulate the development of some high energy-consuming industries, so carbon emissions will rise. In addition, there are many reasons for the rise in unemployment. On the one hand, there is insufficient motivation for capital to stimulate employment and insufficient new jobs. On the other hand, the employment skills of the unemployed are not high. Under the background of carbon neutralization and peak carbon emission goals, some employees with low skill levels eliminated by the polluting production sector in the market in the process of transformation and upgrading cannot improve their skills and comprehensive quality in a short time, so the unemployment rate rises. On this basis, such displaced unemployed people are likely to enter the production sector with higher pollution levels under the condition of a lack of training capital, thus increasing the increase of total carbon emissions (Aceleanu et al., 2015).

Although the green finance development level has ranked first in the world, it is still being promoted in the form of the pilot in China, which still cannot meet the market demand. Therefore, the support of green finance to stabilize employment in green transformation is still insufficient, which makes the mobility of market labor in different sectors low and industrial structure upgrading less efficient, thus delaying the green transformation of the economy and detrimental to carbon emission reduction. It is also worth noting that most of the environmental protection, low-carbon, and green production departments in the market are science and technology-based, small and medium-sized enterprises, which have the characteristics of high investment, high risk, and long cycle (Machiba, 2011). Therefore, enterprises usually cannot fully absorb the unemployed, but control the development scale and reduce the employed due to capital constraints. In the short term, such unemployed people are likely to be squeezed out of highly polluting production sectors, which is not conducive to the improvement of industrial structure and energy structure, and finally stimulate the increase of carbon emissions (Zhou et al., 2013). Based on this, the following hypothesis is proposed in this study.

Hypothesis 3. The rise of the unemployment rate promotes carbon emissions.

Based on the above research, this study summarizes the following research gaps: firstly, the current literature pays more attention to the research on financial development and carbon emissions, while the research on green finance and carbon emissions stays at the theoretical level. Secondly, although some scholars study the relationship between green finance and carbon emissions, few scholars take the unemployment rate as a

TABLE 1 Descriptive statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
$lnCO_2$	480	1.030	0.783	−1.833	2.714
gfi	480	0.146	0.099	0.000	0.793
ur	480	3.449	0.741	0.000	6.500
open	480	0.268	0.304	0.010	1.457
lnpgdp	480	1.169	0.699	−0.864	2.799
eri	480	0.517	0.529	0.000	2.585
financeim	480	2.948	1.147	1.400	7.900

Note: CO_2, carbon emission; gfi, green finance; ur, unemployment rate; open, economic openness; pgdp, economic growth; eri, environmental regulation; financeim, financial development level.

TABLE 2 Cross-sectional dependence test results.

Variables	Pesaran CD-test	*p*-value
$lnCO_2$	61.604	0.000
gfi	83.061	0.000
open	78.786	0.000
lnpgdp	80.145	0.000
eri	66.025	0.000
financeim	82.762	0.000

mediating variable to expand their research. Finally, the research on the regional heterogeneity of green finance on carbon emissions needs to be supplemented to promote the coordinated development of China's carbon emissions.

3 Methodology

3.1 Model establishment

3.1.1 OLS panel regression model construction

Under the premise that other variables are controlled for their effects on carbon emissions, following the study findings and empirical norms of Bai et al. (2022), this study examines the effects of green finance on carbon emissions. The model is set up in the following form:

$$lnCO_{2it} = a_0 + \beta_1 gfi_{it} + \beta_2 open_{it} + \beta_3 ln\,pgdp_{it} + \beta_4 eri_{it} + \beta_5 financeim_{it} + \varepsilon_{it} \quad (1)$$

where i represents the area and t represents the year; $lnCO_{2it}$ refers to the explained variable and represents carbon emissions after taking the natural logarithm.; gfi_{it} is the core explanatory variable and represents the green financial level of the region i in the year t; a_0 is a constant, $\beta_1 \sim \beta_5$ are the coefficients of the relevant influencing factors; $open$ represents the degree of local openness; $ln\,pgdp$ represents the local per capita nominal GDP; eri represents environmental regulation; $financem$ denotes financial development level; ε is the random error term.

3.1.2 Generalized method of moments

However, OLS is a static regression model and does not consider endogeneity among variables. To further explore the dynamic relationship between carbon emissions and green finance, this study lags carbon emissions by one period and applies a dynamic panel regression model. The specific model is as follows:

$$lnCO_{2it} = a_0 + \beta_1 lnCO_{2it-1} + \beta_2 gfi_{it} + \beta_3 open_{it} + \beta_4 ln\,pgdp_{it} + \beta_5 eri_{it} + \beta_6 financeim_{it} + \varepsilon_{it} \quad (2)$$

Among them, $lnCO_{2it-1}$ represents the one-period lagged term of the explained variable. Other variables are set as in Eq. 1.

3.1.3 Construction of mediating effect model

In addition, to verify the mediating effect of employment in green finance and carbon emission, this study sets the following model:

$$lnCO_{2it} = a_0 + \beta_1 gfi_{it} + \beta_2 open_{it} + \beta_3 ln\,pgdp_{it} + \beta_4 eri_{it} + \beta_5 financeim_{it} + \varepsilon_{it} \quad (3)$$

$$ur_{it} = a_0 + \beta_1 gfi_{it} + \beta_2 open_{it} + \beta_3 ln\,pgdp_{it} + \beta_4 eri_{it} + \beta_5 financeim_{it} + \varepsilon_{it} \quad (4)$$

$$lnCO_{2it} = a_0 + \beta_1 gfi_{it} + \beta_2 ur_{it} + \beta_3 open_{it} + \beta_4 ln\,pgdp_{it} + \beta_5 eri_{it} + \beta_6 financeim_{it} + \varepsilon_{it} \quad (5)$$

In Eqs 4 and 5, $ur_{i,t}$ represents the level of unemployment in a region i in a year t. Figure 1 provides the role mechanism of green finance on carbon emissions from the perspective of the unemployment rate.

3.2 Variables description

3.2.1 Explained variable

The explained variable is expressed by carbon emission (CO_2). The measure of carbon emissions is determined by the utilization of 10 energy sources in every area, namely crude coal, coke, unrefined petroleum, gas, lamp oil, diesel, fuel oil, flammable gas, melted oil gas, and power (Chen, 2020; Jiang et al., 2022). The computation recipe is as per the following model:

$$lnCO_{2it} = \sum_{j=1}^{10} lnCO_{2itj} = \sum_{j=1}^{10} ln\,E_{itj} \times Q_j \times \frac{44}{12} \quad (6)$$

In Eq. 6, CO_{2it} represents the total carbon emissions of a province i in a year t; $lnCO_{2itj}$ represents the total carbon emission of the j energy in a province i in a year t. E_{itj} represents energy consumption for type j energy in i province

t year. Q_j is the carbon dioxide emission coefficient of j energy sources, where the carbon emissions coefficient adopts the IPCC standard, and $\ln CO_2$ is used to represent carbon emissions. To eliminate heteroscedasticity and reduce data fluctuation in empirical analysis, the logarithm CO_2 is adopted for analysis.

3.2.2 Core explanatory variable

Concerning Yin et al. (2021), this study constructs green finance (gfi) index system namely green credit, green securities, green insurance, green investment, and carbon finance indicators, and measures the green finance (gfi) index system using the entropy value method.

3.2.3 Control variable

1) Economic growth ($ln\,pgdp$): Economic development can contribute to an increase in the level of green technology, which can have an impact on carbon emissions (Anser et al., 2020b; Yang Z. et al., 2021; Jahanger et al., 2022; Wang et al., 2022a). Following Wang et al. (2022), this study uses per GDP to reflect the level of economic development. To eliminate heteroscedasticity and reduce data fluctuation in empirical analysis, the logarithm of $pgdp$ is adopted for analysis.
2) Economic openness ($open$): Referring to Yang et al. (2021b), the degree of economic openness selects the proportion of the total import and export trade of each province in the GDP of that year to measure the degree of local economic openness.
3) Environmental regulation (eri): Environmental regulation is the public authority's utilization of managerial orders to direct the creation conduct of undertakings, lessen the emission of pollutants, to accomplish the reason for environmental protection, and top-notch economic development. In this study, the complete index of environmental guidelines in every area is determined by the entropy technique from the release of modern wastewater, modern SO_2, and modern residue.
4) Financial development level ($financeim$): Following Cao et al. (2021), the financial development level is estimated by the extent of the harmony between stores and credits of financial organizations in every area in the neighborhood GDP.

3.2.4 Mediating variable

In this study, the mediating variable is measured by the unemployment rate (ur) of each province.

3.3 Descriptive statistics

This study selects 30 provincial panel data of the Chinese mainland from 2004 to 2019 as the research objects. The original data come from the China Statistical Yearbook, China Financial Yearbook, China Environmental Statistical Yearbook, China Industrial Statistics Yearbook, China Insurance Yearbook, China Environmental Statistics Yearbook, the Statistical Yearbook of each province, and Wind database. Descriptive statistics are shown in Table 1.

4 Results and discussion

4.1 Discussion on cross-sectional dependence and slope heterogeneity tests

As marketization continues to increase as well as economic interactions among various areas intensify in frequency, correlations among areas are increasingly significant. Consequently, inconsistency and bias in the estimates arising from the cross-sectional dependence formed by the various areas may occur when examining some economic stories by using the panel data of the composition of the above-mentioned area as methodologically (e.g., Baltagi, 2008; Pesaran, 2015b) and empirically shown (e.g., Baltagi, 2008; Hasanov et al., 2016; Hasanov et al., 2021; Hasanov and Mikayilov, 2021; Liddle and Hasanov, 2022). Referring to Pesaran (2015a) and Hasanov and Mikayilov (2021), the Pesaran test with weak exogenous cross-sectional dependence is examined for the study sample in this study. The test results are shown in Table 2.

However, the FGLS estimation method is able to correct for the heteroscedasticity, cross-sectional correlation, and sequence-correlation problems due to the cross-section data, improving the consistency, and effectiveness of the panel regression. Therefore, this study uses the feasible generalized least squares (FGLS) to substitute the residual vectors of each individual cross-section into the covariance matrix of cross-section heteroscedasticity and uses GLS to obtain the parameter estimates. It is worth noting that when the number of times T in the panel data model is less than the section number N, the standard deviation of the FGLS estimation parameters cannot fully reflect the variation, so the panel-corrected standard errors (PCSE) should be considered to deal with the complex panel error structure. The PCSE method substitutes the residual term into the diagonal matrix by retaining the OLS estimation parameters and correcting its standard deviation, which is an alternative to FGLS and enables a more accurate regression estimation of the panel data. Therefore, to solve the complex panel error structure, the FGLS and PCSE estimates were used to correct the model. Test results are presented in Table 3. The results show that the FGLS and PCSE estimates are essentially the same and are generally consistent with the benchmark regression results, so the benchmark regression results in this study are robust.

TABLE 3 Test results after the correction.

Variable	FGLS	PCSE
gfi	−1.544*** (0.109)	−1.415*** (0.208)
open	−0.133*** (0.014)	0.094 (0.075)
lnpgdp	0.549*** (0.012)	0.183*** (0.053)
eri	0.993*** (0.007)	0.030 (0.019)
financeim	−0.059*** (0.005)	0.021 (0.019)

Standard errors in parentheses; *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.
Note: gfi, green finance; open, economic openness; pgdp, economic growth; eri, environmental regulation; financeim, financial development level.

TABLE 4 Panel unit root test result.

Variables	Level	First difference
$lnCO_2$	−2.415*	−3.817*
gfi	−1.777	−3.057*
open	−1.415	−3.095*
lnpgdp	−0.743*	−2.596
eri	−1.845*	−3.875*
financeim	−1.608	−2.671

The symbols * refer to the level of significance at 10%.

TABLE 5 Pedroni test for cointegration.

		Statistic	*p*-value
Pedroni	Modified Phillips-Perron t	6.6334	0.0000
	Phillips-Perron t	−8.0345	0.0000
	Augmented Dickey-Fuller t	−6.9990	0.0000

TABLE 6 Cointegration results for Westerlund (2007) test.

Statistic	Value	Z-value	*p*-value
Gt	−3.120	−5.212	0.000
Ga	−13.180	−1.056	0.146
Pt	−17.222	−6.580	0.000
Pa	−20.372	−10.470	0.000

TABLE 7 OLS panel regression result.

Variable	(1)	(2)	(3)	(4)	(5)
gfi	**−1.686*** **	**−1.780*** **	**−1.641*** **	**−1.570*** **	**−1.520*** **
	(0.173)	(0.191)	(0.183)	(0.177)	(0.190)
open	—	−0.093	−0.121	−0.095	−0.113
	—	(0.087)	(0.084)	(0.083)	(0.082)
lnpgdp	—	—	0.206***	0.212***	0.271***
	—	—	(0.058)	(0.059)	(0.075)
eri	—	—	—	0.083***	0.082**
	—	—	—	(0.032)	(0.032)
financeim	—	—	—	—	0.042 (0.028)
_cons	0.703***	0.720***	0.752***	0.719***	0.642***
	(0.037)	(0.040)	(0.037)	(0.038)	(0.066)
N	480	480	480	480	480
adj.R-sq	0.971	0.971	0.972	0.972	0.972
AIC	−526	−525.1	−539.8	−544.6	−545.2
BIC	−334	−328.9	−339.5	−340.1	−336.5

Standard errors in parentheses; *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.
Note: gfi, green finance; open, economic openness; pgdp, economic growth; eri, environmental regulation; financeim, financial development level.

4.2 Discussion on panel unit root test and cointegration test results

The variables used in the analysis are often drifting and hence their mean, variance, and covariance change over time (e.g., see Pesaran, 2015b). Therefore, in order to maintain the validity of the econometric test and estimation results the panel data should be subjected to a unit root test to check whether they have stationarity (Baltagi, 2008; Pesaran, 2015b). Following Meo et al. (2020), and Hasanov et al. (2021), the cross-section dependence unit root test proposed by Pesaran (2007), is employed in this study to verify whether there is a unit root for the dataset (see Table 4). Pesaran (2007) suggests that most of the variables are stationary and most of them become stationary after the first difference. After finding the order of integration in the panel, this study also attempts to investigate whether there is a cointegration relationship between the variables (see Tables 5 and 6). Table 5 that Pedroni test is rejected at the 1% level, so there is a cointegration among them, which also implies that the benchmark regression model can be used for the estimation. Besides, Table 6 demonstrates that a null hypothesis of no cointegration cannot be rejected for the results of the Westlund (2007) test that Gt, Pt, and Pa variables are cointegrated, while the remaining one cannot reject the null hypothesis of no cointegration. As Hasanov et al. (2021), the Westlund (2007) test causes under-rejection in small samples.

4.3 Discussion on OLS panel regression result

To add to the robustness of the regression result, this study utilizes the stepwise regression method of progressively expanding the control factors, and increasing the robustness and validity of the results. The time and individual effects were fixed to reduce the impact on estimated results (see Table 7). Table 7 reveals that the coefficients of the core explanatory variable (gfi) are significantly negative at the 1% level; that

TABLE 8 Results of stepwise regression of GMM model.

Variable	(1)	(2)	(3)	(4)	(5)
L1. $lnCO_2$	0.788*** (0.102)	0.776*** (0.118)	0.629*** (0.107)	0.602*** (0.102)	0.574*** (0.112)
gfi	**−12.293** (4.929)**	**−12.520*** (4.890)**	**−12.671*** (4.630)**	**−14.162** (5.804)**	**−15.517** (6.920)**
open	—	−0.239 (0.211)	−0.276 (0.200)	−0.294 (0.209)	−0.392** (0.191)
lnpgdp	—	—	0.129 (0.313)	0.052 (0.353)	0.199 (0.428)
financeim	—	—	—	−0.033 (0.190)	−0.281 (0.033)
eri	—	—	—	—	0.143* (0.081)
AR(2) *p*-value	0.242	0.246	0.230	0.237	0.195
Hansen	0.201	0.267	0.238	0.252	0.232

Standard errors in parentheses; $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

is, the development of green finance has a huge inhibitory effect on carbon emissions. Hypothesis 1 is confirmed. Our results provide similar evidence for the findings of Sun (2021) and Xiong and Sun (2022). It is not difficult to understand that, due to the nature of green finance, it strictly restricts the financing support for high pollution and high energy-consuming enterprises, such as the high-interest rate for loans, so that the expansion of the production scale of such enterprises is restricted, and then through the market mechanism, it forces enterprises to transform and upgrade to reduce the pollution emissions caused by the original production mode (Shen et al., 2021; Meo and Abd, 2022). In addition, by increasing financial support for the development of environmental protection and energy-saving industries, such as the implementation of preferential interest rates on green credit for such industries, capital support for their expansion and reproduction cannot only strengthen the production scale of the original enterprises in the market but also attract other enterprises to enter the industry, reducing carbon emissions from the source (Bai et al., 2022).

4.4 Discussion on panel regression model result

To further verify the dynamic relationship between green finance and carbon emissions, this study introduces the GMM model to alleviate the endogenous problem. Some necessary tests should be required before using the GMM model (see Table 8). Table 8 reports that according to the *p*-value of AR(2), there is no second-order autocorrelation in the random disturbance term. Hansen test results show that there is no over-identification problem of instrumental variables, indicating that the estimation results are effective. The lagged period of the explained variable is significantly positive at the 1% level, implying that carbon emissions in the earlier period will have a positive impact on carbon emissions in the later period. Besides, the core explanatory variable (gfi) is significantly negative at least 1%. Hypothesis 1 is once again tested.

4.5 Discussion on robustness test result

To additionally demonstrate the robustness of the above results, a two-stage least squares test (2SLS) is conducted, and the outcomes are displayed in Table 9. It can be seen that in the process of stepwise 2SLS regression, the contribution of green finance to carbon emissions is significantly negative at the level of 1%. The significance and indication of the core explanatory variable have not changed except for the little difference in the regression coefficient. The openness, per capita GDP, financial development, and environmental regulation are significant at the level of 10%, which is consistent with the results of OLS panel regression and dynamic panel GMM regression. The results of stepwise OLS panel regression, GMM dynamic panel regression, and 2SLS robust regression show that the results of empirical regression are reliable and have good stability. Therefore, the research results of this study are robust.

4.6 Discussion on mediating effect regression result

According to the mediating effect of the unemployment rate on the impact of green finance on carbon emissions, the next test is carried out according to the mediating effect test process. As shown in Table 7, in the bootstrap test, the direct effect and mediating effect are significantly negative at the level of 1%, that is, the direct effect and indirect effect of green finance on carbon emissions are negative, while the Sobel test is significantly negative at the level of 1%, which proves the stability of the mediating effect.

As shown in Table 10, the impact of green finance on carbon emissions in path 1 is significantly negative at the level of 1%, that is, it has a significant inhibitory effect. The indirect regression results of path 2 show that the impact of green finance on the unemployment rate is significantly negative at the level of 1%, therefore, Hypothesis 2 is verified. It can be seen from path 3 that

TABLE 9 Results of robustness test.

Variable	(1)	(2)	(3)	(4)	(5)
gfi	**−1.526*** (0.168)**	**−1.745*** (0.199)**	**−1.713*** (0.193)**	**−1.659*** (0.186)**	**−1.588*** (0.206)**
open	—	−0.175** (0.078)	−0.200*** (0.075)	−0.179** (0.073)	−0.182** (0.073)
lnpgdp	—	—	0.135** (0.055)	0.136** (0.056)	0.181** (0.070)
eri	—	—	—	0.061** (0.030)	0.060** (0.030)
financeim	—	—	—	—	0.029 (0.024)
_cons	1.681*** (0.049)	1.736*** (0.544)	1.525*** (0.106)	1.586*** (0.106)	1.317*** (0.190)

Standard errors in parentheses; *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

TABLE 10 Results of mediating effect regression analysis.

Variable	Path 1	Path 2	Path 3
	$lnCO_2$	**ur**	**$lnCO_2$**
ur	—	—	**0.145*** (0.396)**
gfi	**−1.555*** (0.403)**	**−3.247*** (0.462)**	**−1.085** (0.418)**
open	−0.136* (0.781)	0.256*** (0.895)	−0.173** (0.078)
lnpgdp	0.546*** (0.044)	−0.574 (0.050)	0.554*** (0.049)
eri	1.001*** (0.046)	−0.162*** (0.053)	1.024*** (0.046)
financeim	−0.567* (0.031)	−0.157*** (0.358)	−0.340 (0.031)
_cons	0.286*** (0.794)	4.514*** (0.091)	−0.367* (0.195)

Standard errors in parentheses; *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

TABLE 11 Bootstrap and Soble test.

_bs_1	**−0.470*** (0.156)**
_bs_2	**−1.085*** (0.402)**
Soble	−0.470*** (0.145)
Goodman-1 (Aroian)	−0.470*** (0.146)
Goodman-2	−0.470*** (0.144)

Standard errors in parentheses; *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

the unemployment rate and carbon emissions show a significant positive effect at the level of 1%, that is, the increase in the unemployment rate will increase carbon emissions. Therefore, Hypothesis 3 is verified. Therefore, combining the results in Tables 10 and 11, it is clear that green finance can significantly reduce carbon emissions by diminishing the unemployment rate. One potential explanation is that, ceteris paribus, the financing constraints induced by green finance will raise firms' production costs, thereby reducing their production size and the number of employees they can absorb. However, Porter's hypothesis confirms that in this case, the polluting firm may have a comparative advantage due to the impact on competitors in terms of production process transformation and products. Moreover, the green financial tools currently adopted by China do not directly constrain total carbon emissions, but rather attempt to reduce them by financing adjustments and technological advances. Therefore, if the "use of new technologies" is implicit in this process, then the carbon abatement technology itself generates job creation and thus reduces unemployment. For instance, green finance stimulates the R&D and application of emission reduction technologies, which require additional labor input in the process and thus create some employment opportunities. Also, these abatement technologies may convert by-products (e.g., residues) generated in the production process into commodities, thereby increasing corporate profits and corresponding employment opportunities. This not only further reduces unemployment but also curbs carbon emissions.

In addition, it can be seen from Tables 5 and 6 that a open has a significant inhibitory effect on carbon emissions, but it has a significant promoting effect on *ur*. The reason is that trade opening is conducive to the introduction of foreign advanced technology, which drives domestic technological progress, leads to reduced energy consumption, and ultimately suppresses carbon emissions. However, the improvement of the opening level will promote the import of a large number of foreign talents, thus squeezing the domestic labor market and leading to the rise of *ur*. Economic growth will significantly aggravate the increase of carbon emissions but will not significantly inhibit the rise of *ur*. Because economic growth will promote energy consumption and increase carbon emissions (Li et al., 2022; Wang et al., 2022b). However, economic growth will promote the increase of jobs, thus reducing *ur*. *eri* has a significant positive impact on carbon emissions, but has a significant negative impact on *ur*. When *eri* is at a low level, the production department will follow the cost principle and purchase cleaning equipment, but it also inhibits the development of technological innovation and will eventually promote an increase in carbon emissions. When *eri* is at a high level, the production department will transfer industries with high energy consumption and high pollution

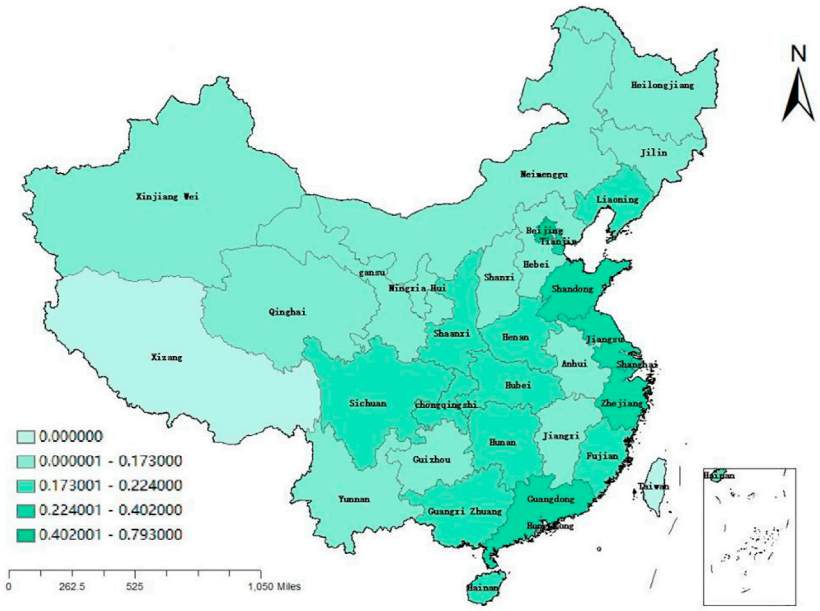

FIGURE 2
2019 Green finance index distribution map.

to areas with preferential policies, thus reducing the constraints of environmental regulation (Wang et al., 2022c). Even in some regions, government departments are engaged in "bottom-by-bottom competition" in order to chase GDP growth, which is not conducive to carbon emission reduction.

4.7 Discussion on regional heterogeneity result

There may also be significant regional heterogeneity in the impact of green finance on carbon emissions in different regions due to their different natural endowments, economic levels,

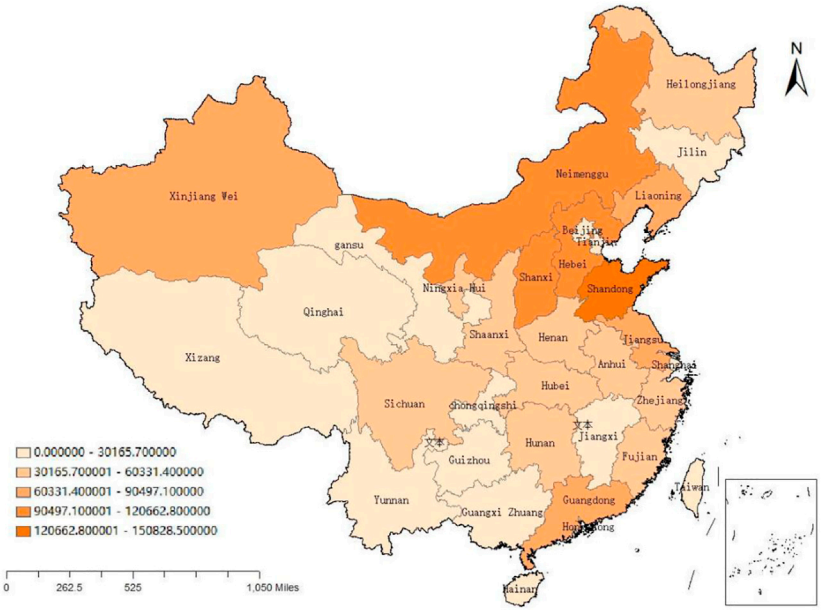

FIGURE 3
2019 Carbon emissions distribution map.

TABLE 12 Regional heterogeneity result.

	Eastern	Central	Western
gfi	**−1.394*** (0.181)**	**−5.259*** (1.040)**	**−1.959 (1.480)**
open	0.253** (0.114)	1.105*** (0.357)	−0.9026*** (0.294)
lnpgdp	0.777*** (0.147)	0.753*** (0.107)	−0.503*** (0.140)
eri	−0.003 (0.037)	0.093** (0.046)	−0.038 (0.083)
financeim	0.064 (0.039)	0.158* (0.076)	−0.137*** (0.048)
_cons	−1.233** (0.487)	0.682*** (0.179)	0.283 (0.208)
N	196	128	176
adj.R-sq	0.990	0.974	0.958
AIC	−310.6	−270.1	−143.9
BIC	−212.3	−190.2	−45.6

Standard errors in parentheses; *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

industrial structures, and policy preferences (Islam et al., 2022; Yang et al., 2022). This study divides China's 30 provinces (cities) into three parts according to the level of economic development: eastern, central, and western (Yang et al., 2021c). The eastern region includes Beijing, Tianjin, Shandong Province, Hebei, Jiangsu, Shanghai, Zhejiang, Fujian, Guangdong, and Hainan; The central region includes Shanxi, Inner Mongolia, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, Hunan, and Guangxi; the western region includes Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang. As shown in Figure 2, there are extraordinary contrasts in the development level of green finance in the eastern, central, and western, and the essential development status shows a pattern of slow decrease to the inland. The development of green finance in the eastern coastal regions is relatively high. The development of the central region is relatively deficient except Hubei Province, Henan Province, and Hunan Province, and the development of green finance in the western region is relatively deficient except Sichuan Province and Chongqing. However, there are differences in carbon emissions. According to Figure 3, carbon emissions are relatively high in the central region, especially Shanxi Province and Inner Mongolia in the central region, Hebei Province, and Shandong Province in the eastern region, and moderate in some eastern coastal provinces and developed regions such as Beijing, Shanghai, Zhejiang Province, and Fujian Province.

On this basis, this study uses the OLS model to analyze the regional heterogeneity of the impact of green finance on carbon emissions in eastern, central, and western regions. Table 12 shows that green finance has a significant inhibitory effect on carbon emissions in the eastern and central regions at the level of 1% but insignificant in the western region. One potential reason is that the eastern region mainly gathers political, economic, and cultural centers, and the economic level is relatively developed (Yan et al., 2021). Therefore, the development of green finance can be better supported in the eastern region. However, the local industrial structure is biased toward the tertiary industry, with the majority of high-tech industries, a high level of technological innovation, high energy efficiency, and low carbon emissions compared with the central region (Baloch et al., 2020). Therefore, the inhibitory effect of green finance on carbon dioxide emission is less than that of the central region. Besides, the central region has a relatively dense population, high pressure of employment competition, and many high energy-consuming industries, such as coal, steel, and other industries. Therefore, green finance has a greater impact on the industries in the central region to promote the green transformation and upgrading of industries. With the support of green financial development, the employment pressure can also be better alleviated, to reduce the unemployment rate in the central region, and further curb carbon emissions. Therefore, it has a stronger effect on restraining carbon emissions. Finally, the development level of green finance in the western region is relatively low, coupled with its vast territory and sparse population, the energy demand is relatively low compared with the eastern and middle regions, and the ecological environment is high. Therefore, the inhibitory effect of green finance on carbon emissions is insignificant.

5 Conclusions and policy recommendations

Using the panel data of 30 provincial administrative regions in China from 2004 to 2019, this study investigates the impact of green finance on carbon emissions based on an unemployment rate perspective. This study takes the unemployment rate as the mediating variable to study the impact of green finance on carbon emissions for the first time, which enriches the current research path and theoretical basis and provides more empirical reference evidence for realizing the dual carbon goal. The statistical results found that green finance has a significant inhibitory impact on carbon emissions. Green finance has significantly reduced the unemployment rate. The unemployment rate has a significant positive effect on carbon emissions. Green finance can reduce carbon emissions by diminishing the unemployment rate. There is regional heterogeneity in the effect of green finance on carbon emissions in eastern, middle, and western China. Specifically, green finance in the eastern and central regions significantly inhibits carbon emissions, while in the western region not significantly. In response to the above findings, the study draws corresponding strategic recommendations.

First, speeding up the improvement of the green finance standard framework and motivation and limitation instrument. Policymakers should continue to establish a more effective green financial incentive system, and guide financial resources to green and low-carbon projects. Besides, policymakers should accelerate research on the establishment of emission reduction support tools and encourage the financial sector to increase support for green and low-carbon projects with significant emission

reductions. Through innovation sharing, policymakers can actively cultivate green finance, speed up the reform of energy-intensive industries, and achieve carbon emission reduction.

Second, policymakers should utilize the green finance funding leverage and channeling effect to drive the rapid development of low-carbon, zero-carbon, and carbon-negative industries to develop a scale effect to expand employment. Furthermore, policymakers should play the substitution effect of green finance to accelerate the migration of workers from coal, steel, oil, and other industries to low-carbon industries to optimize the labor market and thus achieve stable employment rates. Finally, policymakers shall employ green finance to increase wages and subsidies for those employed in low-carbon industries, thereby promoting employment for the purpose of indirectly reducing carbon emissions.

Third, policymakers should find out the development process of green finance according to local conditions, formulate green financial development plans accurately according to the actual situation of each region and the attributes of industrial construction, and implement financial and industrial policies following local conditions. Economically developed areas should make use of their developed financial level to vigorously develop green finance and infiltrate into areas, where the green financial level is underdeveloped to achieve the role of a bellwether. While implementing green finance, the central and western regions should optimize the existing green finance development policies by drawing on the advanced experience of the eastern regions, thereby maximizing carbon emission reduction.

However, this study still has some limitations. Firstly, it is only based on China's inter-provincial panel data, and other countries may have the same problems, so future research can be expanded to international research samples. Secondly, it lacks case analysis. Future research can further support the research conclusion of this study by investigating the pilot efficiency of green finance policy. Finally, the impact of green finance on carbon emissions may have a nonlinear relationship, so future scholars can deepen this research by adding threshold variables.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding authors.

Author contributions

YC: Conceptualization, Project administration, Formal analysis, Writing—review and editing, Data curation, Writing—original draft. GW: Software, Visualization, Conceptualization, Methodology. MI: Writing—original draft, Writing—review, and editing, Formal analysis, Validation. DW: Writing—review and editing, Validation. JC: Writing—review and editing, Writing—original draft, Conceptualization, Methodology, Funding acquisition, Supervision.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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