The carbon reduction effect of China’s outward foreign direct investment for carbon neutrality target

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Abstract
Based on mainland China’s provincial OFDI and carbon emissions data from 2003 to 2018, this paper applied a panel fixed-effects model and spatial econometric model to empirically test whether China’s OFDI can be a powerful tool to achieve the “carbon neutrality” target. The empirical results indicate that China’s OFDI significantly increases carbon emissions, but this effect has temporal and spatial differences. After incorporating spatial factors into the analysis, the impact of OFDI on carbon emissions differs when modelled by different spatial weight matrices. The green effect of OFDI has the problem of poor channels. It is impossible to achieve energy savings and emission reduction by promoting green technology innovation, improving the rationalization of the industrial structure or reducing energy consumption. The test results of the moderating effect indicate that the development of green finance can weaken the positive effect of OFDI on emissions.

Keywords OFDI · Carbon emissions · Green technology innovation · Energy consumption · Green finance

Introduction
Since the 1970s, China’s economy has gradually integrated into the global market. From the early days of attracting foreign direct investment (FDI) to the subsequent acceleration of the pace of “going out”, after a period of exploration and development, China’s outward direct investment (OFDI) has ushered in a period of deepening. The total amount of China’s OFDI exceeded US$10 billion for the first time in 2005 and US$100 billion in 2013 and then entered a stable development trend. Against the backdrop of the coronavirus and the “unprecedented changes” in international conditions, the scale of China’s OFDI (flows) reached $153.71 billion, the world’s largest origin of investment in 2020.

China’s rapid economic growth has been accompanied by high environmental costs. The Outline of the 14th Five-Year Plan for National Economic and Social Development of the People’s Republic of China, released in 2020, recognizes the significant improvement in China’s ecological environment while noting that China still has a “long way to go” in terms of environmental protection. It is now well established that environmental pollution can impair the quality of life (Ebenstein et al. 2015; Sinharay et al. 2018), reduce subjective feelings of well-being (Keller and Levinson 2002) and even increase the incidence of violent crime (Burkhardt et al. 2019). At the economic level, environmental pollution could lower business productivity (Greenstone 2002) as well as labour productivity (Zivin and Neidell 2014). The climate change caused by greenhouse gas emissions is one of the most important environmental problems we are facing. International initiatives such as the Paris Agreement and The Intergovernmental Panel on Climate Change (IPCC)’s Special Report on Global Warming of 1.5 °C have set clear targets for activities to reduce global carbon emissions (Mitchell et al. 2017), based on which many countries have further defined and strengthened their autonomous targets, demonstrating their determination to work together. In 2020, China proposed its “double control” target; that is, China plans to reach its peak carbon emissions by 2030 and achieve carbon neutrality by 2060. As the world’s largest emitter of carbon dioxide in 2020, the “double control” target presents China’s determination and ambition to control carbon emissions. “Carbon neutrality” refers to offsetting

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carbon emissions through afforestation, carbon capture and storage technologies to achieve “net zero”. However, in the near future, the capacity of carbon sequestration will be limited, and its technical feasibility needs further examination. The emission reduction will still be the major contributor to achieving carbon neutrality instead of increasing carbon sequestration. Therefore, the path to achieve carbon neutrality will be a comprehensive economic and social system reform, requiring tremendous efforts from every sector of society.

While carrying the international flow of capital, OFDI also carries the transfer of technology and industries internationally, which will have an important impact on China’s carbon emission reform. In the context of the expanding scale of OFDI and the very urgent task of carbon emission reduction, this paper focuses on the relationship between China’s OFDI and carbon emissions.

The remaining part of the paper is presented as follows: “Literature review and theoretical framework” section discusses the theoretical basis and literature; “Methodology and data” section provides a detailed description and explanation of the data and models used in this paper; “Empirical results and discussion” section presents the findings of the research; and “Conclusions and policy implications” section provides the conclusions and policy recommendations.

**Literature review and theoretical framework**

**Impact of OFDI on carbon emissions**

How to balance economic development and environmental quality is always a hot topic among scholars and policymakers. At present, most of the existing studies focus on the relationship between economic growth or foreign direct investment and the environment, but the conclusions are not consistent.

There are few studies on the environmental pollution of OFDI in the home country, and most studies believe that OFDI does not directly affect the environment but its effect occurs through certain channels. Yang and Liu (2013) believed that the increase in OFDI in Japan reduces CO₂ emissions and that OFDI will improve the environmental condition. Similarly, Cozza et al. (2015) studied the relationship between OFDI and the ecological environment from the perspective of the impact of OFDI on the productivity of domestic enterprises and believed that OFDI improved the level of total factor productivity of enterprises and was conducive to alleviating the pressure of environmental pollution. However, Ghosh and Wang (2009) argued that the larger the scale of OFDI in a country, the more frequent are the domestic economic activities, thus causing pollution to the ecological environment of the home country. That is, the scale effect of OFDI aggravates the degradation of the environment. Most scholars believe that China’s OFDI, as an important tool for the “going out” policy, can improve the home country’s environment (Zhou and Li 2021; Hao et al. 2020; Luo et al. 2020). Xin and Zhang (2020) argued that there is a threshold for this effect; hence, only when China’s OFDI exceeds a certain threshold can it play a positive role in curbing emissions. Jiang et al. (2021) found that China’s OFDI can play a positive role in reducing emissions, but others reached opposite conclusions (Yang et al. 2021). In conclusion, whether foreign or Chinese, research on the relationship between OFDI and the home country environment is still insufficient and has not reached consistent conclusions.

**Mechanism analysis of OFDI’s impact on carbon emissions**

**Reverse technology spillover effect**

Green technology innovation and environmental protection are closely linked, and new eco-friendly technologies and products could provide new methods to address environmental issues. Green innovation also decreases the cost of enterprises to apply clean technologies, which facilitates the use of clean production and helps reduce emissions. Green innovation can also improve production efficiency, reduce energy consumption with constant output and relieve environmental pressure by recycling resources (Andreoni and Levinson 2001).

The theory of “reverse technology spillover” suggests that enterprises of the home country could transfer advanced technologies from the host country through OFDI and at the same time obtain income from overseas investments, which provides the necessary financial and technical support for the home country’s green production upgrading and for conducting R&D investment. The international R&D model constructed by Coe and Helpman (1995), referred to as the C-H model, explores technology spillover effects, emphasizing that the improvement of a country’s innovation capability should not only rely on domestic resources but also make full use of international technological resources. After that, Torres (2015), Mani (2013) and Jeenanunta et al. (2013) took the foreign investment of India, the UK, Japan and Thailand as the research objects and explored the existence of the reverse technical effect of OFDI. As a result, it can reduce energy consumption in the production process and improve resource utilization and the capability of pollutant removal, which benefit the environmental quality of the home country (Bai et al. 2020; Luo et al. 2021). Although most literature affirms the motivation of Chinese OFDI to acquire foreign strategic resources, Zhou et al. (2019), however, found that China’s OFDI does have reverse technology
spillover effects, but this effect shows large heterogeneity across provinces due to the lack of necessary supporting conditions and significant development differences. Even with the dramatic rise in the scale of OFDI, its impact on the local development of the green economy is limited. Moreover, research has found that whether China’s OFDI has a positive reverse technology spillover effect depends on the development status of the host country. When OFDI targets developed countries, it is more likely to exert a technology upgrading effect, while this effect is less significant for firms investing in developing countries (Hong et al. 2019; Chen et al. 2020).

**Rationalization and upgrading of industrial structure**

Kojima’s (2005) “marginal industry expansion theory” suggests that industries that have comparative disadvantages in their home country can use the OFDI channel for technology transfer to other countries to optimize the domestic industrial structure and resource allocation. This optimization of industrial structure implies a shift of home country industries from labour-intensive and resource-intensive industries to technology-intensive industries, and the total volume and proportion of tertiary industries subsequently increase. Hiley (1999) found that by transferring traditional industries such as the textile industry to Southeast Asian countries, Japan provided factor resources for the development of emerging industries and promoted the upgrading of Japan’s industrial structure. Similarly, Barrios et al. (2004) took Ireland as the research object, and Filip et al. (2014) took Taiwan and Japan as samples; they both proved that OFDI has a positive effect on the upgrading of the industrial structure of the home country.

Substantial evidence shows that China’s industrial structure is dominated by heavy industries, which will aggravate environmental degradation (Chen and Zhao, 2019). Padilla-Perez and Nogueira (2016) believed that foreign investment in developing countries has a strategic motive, which makes the direct investment of developing countries with such motives flows to developed countries and promotes the upgrading of the domestic industrial structure. Industrial upgrading can also improve resource efficiency, thereby alleviating domestic environmental pressure. Previous literature has discussed the relation between China’s industrial structure and the environment, but the impact of OFDI is less mentioned (Chen et al. 2019; Zhang et al. 2020). Among the studies exploring the relationship between industrial structure and carbon emissions, Li et al. (2017) concluded that the rationalization, transformation and upgrading of industrial structure in China can significantly reduce carbon emissions. Zheng et al. (2020) indicated that the impact of industrial structure on carbon emissions varies from year to year in different regions of China. The interregional differences in industry, construction, transportation and storage had a significant impact on carbon emissions.

**Energy consumption**

Energy consumption is an important cause of environmental degradation in both developed and developing countries (Soytas et al. 2007; Waheed et al. 2019). China’s energy consumption is dominated by coal, and the CO₂ emissions from coal combustion are particularly serious. The improvement of the environment depends largely on the adjustment of the energy structure. China is developing green and clean energy, but it takes time to completely replace fossil energy (Zhang and Cheng, 2009; Wu et al. 2021).

The resource-acquisition OFDI can acquire overseas resources, change the domestic production input structure and reduce the dependence on domestic natural resources. China’s OFDI to developing countries is mainly resource seeking, which aims to obtain abundant production resources (Ren and Yang 2020). Zhao et al. (2020) examined the relationship between OFDI in China’s energy sector and energy security. The results show that every 1% increase in a country’s energy OFDI leads to a 1.2% increase in the likelihood of imports from that country and a 0.071% increase in firm-level imports. If OFDI can alleviate the pressure on domestic resources, then the unit cost of production using resources will be lower, and increased energy efficiency stimulates consumers and producers to use more energy, causing the “energy rebound” effect. The existence of the rebound effect promotes the increase in total energy consumption in China (Lin and Liu 2012) and partially offsets the reduction in carbon emissions from energy efficiency improvement. Thus, China’s OFDI may negatively impact the environment by increasing energy consumption. Therefore, the impact direction of China’s current OFDI motivated by natural resource seeking on the environment may be uncertain.

**Analysis of green finance’s impact on OFDI and carbon emissions**

Environmental governance should rely not only on mandatory measures but also on financial measures to encourage the green economy. Green finance is rapidly becoming a key instrument that can achieve a “win–win” situation for both the economy and the environment (Salazar 1998). There are also studies pointing out that the development of green finance can improve the social responsibility of financial institutions and contribute to the long-term and stable development of enterprises (Chami et al. 2002; Scholtens and Dam 2007). Developed countries have decades of experience with green finance, and it has played a significant role in promoting economic transformation and sustainable development. The development of green finance in China is still
in the exploration stage and has great potential (Wang et al. 2021a, b).

Since the development of green finance started late, research on the relationship between finance and the environment has focused on the perspective of traditional finance. Current research on the effects of green finance focuses on green innovation activities (Yu et al. 2021), industrial transformation and upgrading efficiency (Gu et al. 2021), economic growth quality (Zhou et al. 2020) and the behaviour of enterprises (Jin et al. 2021; Peng et al. 2021). In the research on the relationship between China’s green finance and pollution, many believe that China’s green finance has played a positive role. Zhou et al. (2020) used 30 provinces and cities in China from 2010 to 2017 as samples to study the impact of green finance on environmental quality, and the findings affirm the positive effects of green finance. Zhang and Vigne (2021) used data from 2005 to 2013 of manufacturing firms in Jiangsu Province of China to assess the impact of green loan policy, an emission reduction policy tool, on firm performance. The study found that China’s green loan policy penalized the performance of high-polluting companies and played a role in limiting emissions. Similarly, Zhang et al. (2021) reached a similar conclusion. Wang et al. (2021a, b) studied the impact of green finance on high-quality energy development in the Yangtze River Economic Belt in China and believed that green finance not only significantly improved the quality of energy development in the region but also had positive spatial spillover effects. The positive impact of green finance on the environment is affirmed.

Overall, there are no consistent conclusions on the relationship between OFDI and carbon emissions in China. Theoretically, OFDI plays a positive role in reversing technology spillover effects, promoting industrial structure optimization and upgrading. OFDI also changes the resource structure of home countries. However, little attention has been given to the three channels of OFDI’s impact on the home country’s carbon emissions, and there is insufficient literature discussing the environmental effects of green finance. This study sheds light on the following three aspects. First, this research takes China’s OFDI as a dynamic trigger of domestic carbon emissions and considers the spatial correlation of carbon emissions. Second, this research identifies the transmission paths of OFDI on carbon emissions by using green technology innovation, industrial structure rationalization and energy consumption as mediating variables and discusses whether OFDI can contribute to the realization of “carbon neutrality” through the above three paths. Third, using the green finance development index as a moderating variable, this research examined the role of China’s green finance in the relationship between OFDI and carbon emissions. This research provides some empirical evidence for the green effects of China’s OFDI, enriches the study of the relationship between economic development and environmental pollution and investigates whether green finance can promote the flow of financial resources to low-carbon green industries and serve the goal of “carbon neutrality”.

### Methodology and data

#### Econometric model

**Panel fixed-effects model**

To systematically analyse the impact of OFDI on carbon emissions, the following fixed-effects panel model is constructed.

\[
\ln CO_{2it} = \beta_0 + \beta_1 \ln OFDI_{it} + \beta_2 \ln ER_{it} + \beta_3 \ln KL_{it} + \beta_4 \ln URB_{it} + \beta_5 \ln TO_{it} + \beta_6 \ln CO_{2it-1} + \delta_i + \gamma_t + \epsilon_{it}
\]

where the subscript \(i\) denotes the region and \(t\) denotes the year. \(\ln CO_{2it}\) represents the carbon emissions of region \(i\) in year \(t\); \(\ln OFDI_{it}\) denotes the OFDI flow of region \(i\) in year \(t\); \(\delta_i\) is regional fixed effects; \(\gamma_t\) is time fixed effects; and \(\epsilon_{it}\) is the error term. The control variables include environmental regulation (\(ER_{it}\)), capital stock per capita (\(\ln KL_{it}\)), urbanization rate (\(URB_{it}\)), foreign trade dependence (\(TO_{it}\)) and lagged one-period carbon emission data (\(L.\ln CO_{2it}\)).

**Spatial econometric model**

Due to the spatial spillover of carbon dioxide emissions, regional carbon emissions tend to have certain clustering characteristics, so adding spatial factors to the baseline regression Eq. (1) can further explore the impact of OFDI on carbon emissions. The spatial econometric models are divided into the spatial error model (SEM), spatial lag model (SLM) and spatial Durbin model (SDM). After the LM test, Hausman test, LR test and Wald test, this paper chooses the spatial Durbin model with double fixed effects, and the specific model is constructed as follows.

\[
\ln CO_{2it} = \beta_1 W_{ij} \ln CO_{2it} + \beta_2 \ln OFDI_{it} + \beta_3 W_{ij} \ln OFDI_{it} + \beta_4 X_{it} + \beta_5 W_{ij} X_{it} + \delta_i + \gamma_t + \epsilon_{it}
\]

where \(W_{ij}\) is a \(30 \times 30\) spatial weight matrix, and three spatial matrices are used in the analysis. The first is a 0–1 spatial adjacency weight matrix, which takes the value of 1 if province \(i\) is adjacent to province \(j\) and 0 if vice versa. The second is a spatial geographic distance weight matrix; if \(i \neq j\), then \(W_{ij} = \frac{1}{d_{ij}}\), where \(d_{ij}\) indicates the distance between two provinces determined by latitude and longitude, when \(i = j\) takes the value of 0. The third is the economic distance...
weight matrix indicating the regional economic development gap. If \( i \neq j \), then \( W_{ij} = \frac{1}{|g_i - g_j|} \) where \(|g_i - g_j|\) is the economic distance of two provinces, calculated by the gap of GDP per capita, when \( i = j \) the value is taken as 0. \( X_{it} \) is a set of control variables.

**Intermediary mechanism model**

With the possible mechanisms of OFDI on carbon emissions discussed in the theoretical analysis section, the following spatial panel model is constructed for empirical tests:

\[
M_{it} = \beta_1 W_{ij} M_{it} + \beta_2 \ln\text{ofdi}_{it} + \beta_3 W_{ij} \ln\text{ofdi}_{it} \\
+ \beta_4 X_{it} + \beta_5 W_{ij} X_{it} + \delta_i + \gamma_t + \epsilon_{it}
\]

\[
\ln\text{CO}_{2it} = \beta_1 W_{ij} \ln\text{CO}_{2it} + \beta_2 \ln\text{ofdi}_{it} + \beta_3 W_{ij} \ln\text{ofdi}_{it} + \beta_4 M_{it} \\
+ \beta_5 W_{ij} M_{it} + \beta_6 X_{it} + \beta_7 W_{ij} X_{it} + \delta_i + \gamma_t + \epsilon_{it}
\]

where \( M_{it} \) is the mediating variable, including three influence mechanisms: green technological progress (\( \text{GTP}_{it} \)), industrial structure rationalization (\( \text{ISR}_{it} \)) and energy consumption (\( \ln\text{EC}_{it} \)).

**Regulating mechanism model**

To further investigate what moderating effect of green finance exists between Chinese OFDI and carbon emissions, two variables, green finance (\( \text{GF}_{it} \)) and the interaction term between OFDI and green finance (\( \ln\text{ofdi} \ast \text{GF} \), are added to the spatial econometric model:

\[
\ln\text{CO}_{2it} = \beta_1 W_{ij} \ln\text{CO}_{2it} + \beta_2 \ln\text{ofdi}_{it} + \beta_3 W_{ij} \ln\text{ofdi}_{it} + \beta_4 \text{GF}_{it} + \beta_5 W_{ij} \text{GF}_{it} + \beta_6 \ln\text{ofdi} \ast \text{GF}_{it} + \beta_7 \ln\text{ofdi} \ast \text{GF}_{it} + \beta_8 X_{it} + \beta_9 W_{ij} X_{it} + \delta_i + \gamma_t + \epsilon_{it}
\]

\[
\text{ISR}_{it} = \sum_{j=1}^{n} \left( \frac{Y_j}{T_i} \right) \ln \left( \frac{Y_j}{T_j} \right), \text{where } Y \text{ denotes the total value added; } Y_j \text{ means value added grouped by three economic sectors; } L \text{ is total employment; and } L_i \text{ is the employment grouped by three economic sectors. Energy consumption (lnEC}_{it} \text{ represents the logarithm of total energy consumption.}

In the intermediary mechanism model, the moderating variable is the green finance index (\( \text{GF}_{it} \)), which is calculated by the entropy method based on four indicators: green credit, green investment, green insurance and government support. Green credit is defined as the percentage of interest expenditure in energy-intensive industries; green investment is measured by the proportion of pollution prevention investment to GDP; green insurance is defined by the scale of agricultural insurance and the payout rate of agricultural insurance; and government support is measured by the percentage of fiscal expenditure on environmental protection.
Control variables

To minimize the problem of endogeneity caused by omitted variables, the following factors that may affect carbon emissions are considered: environmental regulation ($ER_t$) is measured by the proportion of pollution control costs to GDP; per capita capital stock ($lnKL_t$) is measured by the logarithm of the ratio of fixed capital stock to total population, and the stock of fixed capital is estimated by the perpetual inventory method, with 2003 as the base period and the depreciation rate is 9.6%; urbanization rate ($URB_t$) is measured by the provincial proportion of the nonfarm resident population to the total population; foreign trade dependence ($TO_t$) is measured by the ratio of import and export to GDP; and lagged one-period carbon emission data ($L.lnCO2_t$) is applied to indicate the cumulative carbon emissions over time.

Data

Taking 30 provincial-level administrative regions in mainland China from 2003 to 2018 as the research subjects (Tibet, Taiwan, Hong Kong and Macao were excluded due to serious data deficiencies), data were obtained from the provincial statistical yearbooks, the China Energy Statistical Yearbook, the China Statistical Yearbook, the China Environmental Statistical Yearbook, the China Insurance Yearbook and the China State Intellectual Property Office Patent Database. All price data are normalized to the level of 2003 by the GDP deflator (Table 1).

Empirical results and discussion

Fixed-effects panel model

The results, as shown in Table 2, indicate that China’s OFDI significantly increases domestic carbon emissions. When only considering the effect of OFDI on carbon emissions as in column (1), for every 1% increase in OFDI, carbon emissions will increase 0.131%. After adding a series of control variables in column (2), this negative environmental impact is reduced to 0.014%, but the result is still significant. There are two reasons for this observation.

First, China’s OFDI started later than IFDI; in the early days of the reform and opening up, China attracted a number of low-end manufacturing industries from developed countries by virtue of its abundant and cheap production factors. Local governments, under financial and development pressure, often compete with each other, lowering the foreign investment access requirements to attract foreign investment. Such foreign investment not only fails to play a positive role in environmental improvement but also increases the demand for energy and resources, which has a negative impact on the environment. China’s OFDI has developed rapidly in recent decades, but there is still a large gap between the OFDI scale and the IFDI, and the role of changing the negative environmental impact brought by the IFDI is limited. Second, even if long-term investment such as OFDI can theoretically alleviate environmental pressure in home countries, it takes some time for it to have an impact on carbon emissions through various mechanisms, which limits the current green effect of OFDI.

Heterogeneity test

Heterogeneity analysis based on temporal characteristics

In 2013, China experienced a serious “haze crisis”, in which the shortcomings of earlier economic development at the expense of the environment were exposed and the ecosystem was at risk of degradation, which not only threatened people’s physical and mental health but also negatively affected social and economic activities. In 2013, the Chinese government issued the Action Plan for the Prevention and Control of Air Pollution, which proposed ten measures to control air pollution and began strict environmental regulations at the national level. In the same year, China opened China’s first carbon trading market in Shenzhen, reflecting that China began to use market methods to reduce emissions. June 17, 2013, was also the first “National Low Carbon Day” in China, aiming to promote the concept of low carbon to the general public. A series of policy initiatives have reflected the Chinese government’s determination for environmental management. Based on the differences in temporal characteristics, this section of the study further takes into account the time lag in which policy functions, and the overall sample is divided into two parts by 2015 to explore the heterogeneity.
of the impact of OFDI on carbon emissions. According to the results in columns (3) and (4), every 1% rise in OFDI before 2015 significantly drives a 0.012% increase in carbon emissions, but after 2015, OFDI exerts a positive environmental effect of emission reduction. In general, it is clear that China’s comprehensive environmental regulatory policies and high-quality OFDI target interacted to play a positive role in environmental improvement.

**Heterogeneity analysis based on spatial features**

Because China’s economic regional development is unbalanced, this section divides China’s provinces into eastern, central and western regions according to geographical location and further examines whether the impact of China’s OFDI on carbon emissions is regionally different. The results of columns (5) and (6) show that China’s OFDI significantly inhibits carbon emissions in the eastern region but still shows a significant boost to the central and western regions. There are several possible explanations for this result. China’s eastern region was the first to carry out reform and opening up policies, and the level of economic development and the scale of OFDI are much higher than those in the central and western regions. Relying on the advantages of policies, geographical location, high-end talent mobilization and high-tech industry density, the eastern region has the ability to make full use of external markets and resources to achieve industrial upgrading and economic transformational development. Therefore, large-scale OFDI in the eastern region also relies on these advantages to give full play to the positive role of energy conservation and emission reduction. Conversely, the size and quality of OFDI in the central and western regions are much lower than that of the eastern region due to their late integration into the international market. At the same time, in addition to natural factors such as geographical location and climate, the demand for economic development in the central and western regions in the middle and early stages of industrialization far exceeds the requirements of protecting the environment due to the shackles of the government’s economic development goals. The central and western regions take the transfer of marginal industries in the eastern region as the main economic development mode, so it is even more unlikely that the leading industries will be transferred overseas through OFDI. Obviously, the green effect of OFDI has not been effectively played in the central and western regions and even significantly exacerbated carbon emissions in these areas.

**Spatial econometric model**

**Moran’s index test**

Theories believe that geographical attributes are correlated with each other in spatial distribution, and there are three
states: agglomerative, random and regular. To analyse the degree of spatial agglomeration and the dynamic leap process of carbon emissions more intuitively, this section uses the spatial autocorrelation Moran’s index and scatter diagram (due to space limitation, only the results of Moran’s index are listed in the paper) to analyse the spatial dependence (due to space limitation, only the results under the spatial adjacency weight matrix are listed in the paper). The value of Moran’s index ranges from $-1$ to 1. Moran’s $I > 0$ indicates positive spatial correlation, and the larger its value, the more obvious the spatial agglomeration; Moran’s $I < 0$ indicates negative spatial correlation, and the smaller its value, the larger the spatial difference; if Moran’s $I = 0$, the space is random. The results in Table 3 show that the Moran’s $I$ of carbon emissions are all highly significant and positive, and the correlation is basically maintained at a relatively stable level, indicating that there is a “club” clustering phenomenon of carbon emissions in China. Therefore, it is necessary to take into account spatial factors and further explore the relationship between OFDI and carbon emissions.

**Regression results of SDM model**

Table 4 shows the results of the spatial Durbin model under three different spatial weights. The effects of the spatial Durbin model can be decomposed into total effect, direct effect and indirect effect. The direct effect is the effect of OFDI on local carbon emissions, including carbon emissions from other regions. The indirect effect indicates the spillover impact of one province’s OFDI on other regions’ carbon emissions. The results indicate that first, from the total effect perspective, the effect of OFDI on carbon emissions is insignificantly suppressed under the spatial adjacency weight matrix and the spatial geographic distance weight matrix, while it is insignificantly promoted under the spatial economic distance weight. Second, the direct effect is significantly positive at the 5% level with all three spatial weight matrices, indicating that OFDI significantly contributes to local carbon emissions when carbon emissions from other regions are taken into account. Finally, the indirect effect is negative under the spatial adjacency weight matrix and the spatial geographic distance weight matrix, while it presents a positive spillover effect on the emission control of provinces. However, it shows an insignificant contribution to carbon emissions with the spatial economic distance weighting matrix. Comparing the regression results of the three spatial weight matrices, it is found that since the spatial relevance of carbon emissions is mainly reflected in geographic distance, the results from the spatial neighbourhood weight matrix and the spatial geographic distance weight matrix are largely similar, while different conclusions are obtained when the economic disparity between regions is used as the weight. The effect of OFDI on local carbon emissions is influenced by the carbon emissions of other regions. For high pollution concentrations, the stronger spatial correlation enhances the negative externality of environmental pollution, exacerbates
the level of carbon emissions in neighbouring regions and strengthens the negative effect of OFDI, while for concentrations with less environmental pollution, this weaker negative externality of carbon emissions weakens this negative effect.

**Analysis of impact mechanisms**

Table 5 shows the results of three intermediate mechanisms for the effect of OFDI on carbon emissions (only the results under the spatial adjacency weight matrix are reported due to space limitation). In terms of the transmission mechanism of green technology innovation, OFDI does not significantly inhibit regional green technology innovation, but green technology innovation can significantly curb carbon emissions. This means that when green technology innovation is used as a mediating variable, the indirect effect is positive. This implies that OFDI increases carbon emissions by inhibiting regional green technology innovation. In terms of the direct effect, the coefficient is significantly negative at the 1% level, but the sign of the coefficients of the direct and indirect effects is different; hence, there is also a “masking effect”.

According to the intermediary regression results, even though OFDI can theoretically contribute to carbon emission reduction through the above three mechanisms, in practice, this positive effect of China’s OFDI on the environment is limited by other factors. First, China’s OFDI to developing countries is mainly in the form of contracted projects, focusing on infrastructure construction industries such as transportation, power engineering and construction but less on environmental protection and information transmission. The technology spillover effect is limited due to the type of investment industries. Enterprises that can invest in developed countries must first meet their relatively higher environmental standards, and it is very likely that these enterprises already have the capability of green technology innovation before investing. Therefore, there is a temporal overlap between the reverse technology spillover effect of OFDI and green technology innovation. Second, China’s industrial structure rationalization progress is still at the early stage, and resource factors mainly flow from the agriculture sector to the manufacturing sector, which is the pollution-intensive sector of the economy. The reality of unbalanced industrial structure rationalization between regions further weakens the green role of OFDI after the spatial factor is included in the analysis. Finally, China’s OFDI has not shifted the domestic energy-intensive industries, and the increase in domestic economic activities caused by OFDI has caused the “energy rebound” effect. Despite the effectiveness of China’s existing sustainable development initiatives and policies, its economy still relies

| Variables | Mechanism 1 | Mechanism 2 | Mechanism 3 |
|-----------|-------------|-------------|-------------|
| lnGTP     | lnGTP       | ISR         | lnEC        |
| lnEC      | lnEC        | ISR         | lnEC        |
| lnofdi    | −0.086      | 0.011       | 0.021***    |
|           | (0.071)     | (0.010)     | (0.007)     |
| lnGTP     | −0.050**    | 0.217**     | 0.025       |
|           | (0.020)     | (0.104)     | (0.107)     |
| ISR       |              | 0.294***    | 0.636***    |
|           |              | (0.062)     | (0.038)     |
| lnEC      |              | 0.502***    | 0.164***    |
|           |              | (0.048)     | (0.065)     |
| Wp        | 0.051        | 0.294***    | 0.636***    |
|           | (0.068)     | (0.062)     | (0.038)     |
| Fixed effects | Y    | Y           | Y           |
| Control variables | Y    | Y           | Y           |

** indicates significance at the 5% level. *** indicates significance at the 1% level
heavily on the development model of trading the environment for the economy; thus, the effect of OFDI on carbon emissions is limited. The initial technology, structure and energy effects of OFDI are insufficient to influence domestic carbon emissions.

Analysis of moderating effects

The previous paper analysed the mechanism of OFDI’s role in exerting environmental effects, but the difference in the degree of regional green finance development also has an impact on the relationship between OFDI and carbon emissions. According to the results in Table 6, the effect of OFDI on carbon emissions under the three spatial weight matrices shows a highly significant contribution at the 1% level, while the development of regional green finance significantly contributes to regional carbon emissions, but the interaction term between OFDI and green finance is prominently negative. The results indicate that the development of green finance markedly weakens the overall negative environmental effect of OFDI. The possible reason for this is that, on the one hand, China’s green finance has been incorporated into the policy system later than most developed countries. On the other hand, the rationality and feasibility of developing countries using administrative means to promote the development of green finance have also been questioned to a certain extent, believing that the government should do something in creating a good development environment, giving full play to the role of the market as much as possible and avoiding too much direct intervention. Thus, when considering the role of green finance on the environment separately, green finance has shown an astonishing role in promoting carbon emissions. However, the interaction between green finance and OFDI is significantly negative, indicating that OFDI and green finance have weakened each other’s negative impact on environmental pollution. This shows that green finance cooperates with OFDI to grasp the industry flow of financial resources and support clean technology transformation to play a positive role in environmental improvement.

Conclusions and policy implications

This paper matches China’s provincial OFDI with carbon emissions and other related data from 2003 to 2018 and examines the relationship and impact mechanisms between OFDI and carbon emissions in China. Based on the spatial spillover effect of carbon emissions, this paper applied the fixed-effects panel model and spatial econometric model in the empirical analysis section. The results indicate that China’s OFDI significantly increases carbon emissions, but there is heterogeneity in this effect based on time and region. In terms of time differences, China’s OFDI does have a significantly positive impact on emission reduction after 2015. In terms of regional differences, China’s OFDI has significantly suppressed carbon emissions in the eastern region, but it exacerbated the problem in the central and western regions. Considering the influence of spatial autocorrelation, OFDI significantly promotes local carbon emissions when taking other regions’ carbon emissions into account. OFDI in one province has a positive spillover effect on emission reduction in neighbouring provinces modelled by the spatial neighbouring weight matrix and spatial geographical distance weight matrix, but it shows an insignificant role in promoting carbon emissions when modelled by the spatial economic distance weight matrix. The results of the intermediate effect test indicate that OFDI promotes an increase in regional carbon emissions through three channels: inhibiting regional green technology innovation, improving industrial structure rationalization and increasing regional energy consumption. Further analysis reveals that the development of green finance significantly weakens the emission-promoting effect of OFDI.

| Variables | Spatial adjacency weight matrix | Spatial geographic distance weight matrix | Spatial economic distance weight matrix |
|-----------|-------------------------------|----------------------------------------|--------------------------------------|
| lnofdi    | 0.067***                      | 0.104***                               | 0.117***                             |
| GF        | 6.405***                      | 7.976***                               | 8.288***                             |
| lnofdi*GF | −0.354**                     | −0.406***                              | −0.378**                             |
| WP        | 0.414***                      | 0.379***                               | 0.165***                             |
| Control variables | Y   | Y                          | Y                                    |
| Fixed effects | Y   | Y                          | Y                                    |

** indicates significance at the 5% level. *** indicates significance at the 1% level
Based on empirical evidence presented in this paper, we believe that high-quality OFDI can be used as a tool to achieve carbon neutrality targets and to construct a green, low-carbon, circular economic system. Therefore, China should rely on the “Belt and Road” initiative to expand investment in countries (regions) along the route. By guiding “going out” enterprises to optimize their global layout, China needs to continue to expand the scale and quality of OFDI. At the same time, the government can also improve the confidence of enterprises to carry out foreign investment through tax incentives, through the provision of foreign market information and through overseas investment risk assessment, to provide support services. The spatial spillover effect and spatial aggregation characteristics of China’s carbon emissions suggest that the positive external green effect depends on the corporation of neighbouring regions. It is necessary for regional governments to uphold the principle of cooperation, establish regional joint prevention and control mechanisms and integrate management resources to achieve “shared governance” of environmental management between provinces and strive to maximize the benefits of OFDI’s external environment.

The government could play an important role in promoting green OFDI, using policies to increase investment in developed economies, supporting overseas investment with green technology-seeking motives and actively guiding OFDI enterprises to carry out green technology innovation. Transfer and upgrade China’s “sunset industries”, release domestic resources for the sustainable development of green, high-tech industries, and constrain carbon emissions by industrial restructuring. By fully utilizing OFDI tools, the government could transform backwards production capacity, enhance the supply capacity of renewable energy, promote the transition of domestic energy consumption to green energy, build a decarbonized and efficient production model and explore a synergistic development model of the economy and environment.

The government could also strengthen the synergy between flexible market regulation and rigid government environmental regulations to achieve the “carbon neutral” goal, emphasizing the importance of green finance in the relationship between OFDI and emission reduction. At the national level, it is necessary to increase policy guidance and regulate the market environment to ensure the positive role of green finance in constraining carbon emissions. At the same time, financial institutions should follow the “Equator Principles”, take environmental value into consideration, design green financial products for the actual needs of enterprises and contribute to the green and sustainable development of the economy. As economic subjects, enterprises should also fulfill their social responsibilities, change production patterns that are not environmentally friendly and raise awareness of environmental risks.

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Data availability The datasets used or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval This article does not contain any studies with human participants or animals performed by any of the authors.

Consent to participate Written informed consent for publication was obtained from all participants.

Consent for publication The article described has not been published before; not considering publishing elsewhere; its publication has been approved by all co-authors; its publication has been approved (acquiesced or publicly approved) by the responsible authority of the institution where it works. The author agrees to publish in the following journals, and agrees to publish articles in the corresponding English journals of Environmental Science and Pollution Research. If the article is accepted for publication, the copyright of English articles will be transferred to Environmental Science and Pollution Research. The author declares that his contribution is original, and that he has full rights to receive this grant. The author requests and assumes responsibility for publishing this material on behalf of any and all co-authors. Copyright transfer covers the exclusive right to copy and distribute articles, including printed matter, translation, photo reproduction, microform, electronic form (offline, online) or any other reproduction of similar nature.

Competing interests The authors declare no competing interests.

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