A nexus study of carbon emissions and financial development in China using the decoupling analysis

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Abstract
Investigating the linkage between financial development (FD) and carbon emissions is important for mitigating climate change. Nevertheless, there is a scarcity of studies investigating how carbon emissions decouple from FD. Here, we investigate the relationship between FD and carbon emissions by using the decoupling model based on cross-province data of China during 2000–2019. Then, we use the decomposition method to analyze the nine drivers of decoupling elasticity of FD and CO2 emissions. We found that China experienced weak decoupling and strong negative decoupling in most years. Only the finance develops at a very high level; the FD had spare capacities to promote the reduction in the carbon emissions. For example, several developed provinces (e.g., Tianjin, Zhejiang, Guangdong) realized strong decoupling after 2012. The reduction in energy intensity and the increase of foreign direct investment promoted the decoupling of FD from carbon emissions. During the financial recession period, developing a bank-based financial market helped the emissions reduction. Once financial crisis is overcome, developing a market-based financial market promoted the decoupling of FD from emissions. This is because that with the fast FD, the development of stock market contributed to emission reductions through technological improvement, while the bank loans inhibited the decoupling process through the expansion of capital-labor inputs. Overall, these results help in the assessment of the emissions impacts of FD and in addressing climate change problems.

Keywords Financial development · Carbon emissions · Decoupling analysis · LMDI · C-D production function

Introduction
With high-quality economic development, market mechanisms have an essential impact on resource allocation, and the financial assistance for economic growth has rapidly increased (Katircioğlu 2012; Kahouli 2017; Ji and Zhang 2019). However, the significant growth of financial support is inseparable from energy supply, as finance contributes to allocate energy resources those are used for social reproduction (Katircioğlu and Taşpinar 2017; Acheampong et al. 2020; Wang et al. 2021a, b). Thus, the integration of finance and energy has become a key factor impacting the environment (Shahbaz et al. 2017; Bui 2020; Shzhbaz et al. 2020). To mitigate the excessive CO2 emissions, some countries highlight the green finance strategies, aiming to develop sustainable economy and finally realize the harmonious development of finance and environment (Ren et al. 2020; Zhang et al. 2020a, b; Li et al. 2021). China has seen booming increase of green finance (Yao et al. 2021; Zhang et al. 2021a), supported by policies and regulations, as she plans to realize emissions peak by 2030 and carbon neutrality by 2060 (Wang and Yan 2022). In 2016, the People’s Bank of China (PBOC) initiated a guideline for the development of green financial systems (Xu and Li 2020). In 2020, the total green loans and green bonds in China reached 1.8 trillion US dollars and 125 billion US dollars, respectively (Zheng et al. 2021b). Under certain background, how financial development (FD) impact carbon emissions is paramount to climate change mitigation.
Theoretically, FD could affect carbon emissions through various channels from the perspective of the real economy (Chang et al. 2019). For example, FD promotes economic growth, and the economic development leads to an increase in energy consumption and carbon emissions (Shahbaz et al. 2012, 2013). FD can provide financial support for heavy industry, helping it expand its production scale and, thus, increasing emissions. Dong et al. (2021), Safi et al. (2021), and Xu et al. (2022) asserted that FD will increase consumer credit and encourage people to spend money on automobiles, household goods, and polluting items which will undoubtedly increase carbon emissions. However, some studies stated that FD can help enterprises invest in low-carbon technology and then reduce carbon emissions (Chang, 2015a, b; Song et al. 2021; Yang and Tang 2021). Aluko and Obalade (2020) found that a well-developed financial system encourages more financing for renewable and advanced technologies at lower costs, increasing investment and sustaining energy demands. Musa et al. (2021) clarified that financial sectors allow industries to easily access finance from the banking sector to invest in advanced technologies and energy-efficient sources, resulting in lower emissions.

The impact of FD on carbon emissions in China has been investigated using the econometric method. Some studies found that the FD reduces China’s carbon emissions (Jalil and Feridun 2011; Umar et al. 2020; Qin et al. 2021), while some studies indicated that the FD stimulated the growth of China’s emissions (Zhang 2011; Shahbaz et al. 2016; Fang et al. 2020). Moreover, some studies found that the FD had no significant relationship with emissions in China (Rauf et al. 2018). Other studies showed mixed results. For example, Liu and Song (2020) found that FD increased the domestic emissions of a given province but decreased the emissions in neighboring provinces. Generally, existing studies using the econometric method obtain inconsistent results (Zhao and Yang 2020). This is first because that they are limited to the selected sample. For example, with different research aims, some studies classified China’s 30 provinces into different regions according to economic development levels (Xiong et al. 2017; Xu et al. 2021a, b) or geographical locations (Li and Wei 2021; Zhao et al. 2021; Shahbaz et al. 2022). Moreover, the level of FD in different periods has different impacts on emissions; especially, some studies are subject to special events (e.g., financial crisis) (Wang et al. 2022). The advantage of using the econometric method is that their results from a given time span are overall and general. However, its disadvantage is that it is difficult to understand the dynamic characteristics of the FD-emissions relationship from the perspective of individual year. As China’s finance is developing fast, its effects on emissions are variable in different years. Thus, it is of significance to explore the dynamic linkage between FD and emissions during a specific period.

Additionally, the selection of FD indicators has influences on the relationship between FD and emissions (Acheampong 2019; Amin et al. 2020). The emissions may be reduced by the expansion of stock market but increased by the growth of bank loans (Wen et al. 2021). This means that the influence of FD on emissions through various financial indicators may be complicated. The Tapio decoupling model establishes a basic principle to identify a temporal relationship between the two variables, which allows for a more detailed classification of the individuals in the sample (Diakoulaki and Mandarak 2007; Wang and Su 2020a, b; Huo et al. 2021). Moreover, the LMDI model can use time-series data to detect proportional changes in the contribution of different driving factors (Ang 2004, 2005, 2015), as it has good properties such as time reversibility, factor reversibility, polymorization, and zero value robustness (Wu et al. 2018; Chen et al. 2020; Liu et al. 2021a). This means that the LMDI model is different from the statistical analysis that needs a robustness study by modifying working parameters. Thus, this method is a more acceptable decomposition model for informing environmental policies, given that the fewer data requirement and flexible application. Therefore, to identify the driving factors impacting the FD-emissions nexus and investigate their evolutionary characteristics, an integration of decoupling model and LMDI model is necessary.

Here, we are interested in addressing following questions: Can the FD increase while carbon emissions decrease simultaneously? What is the impact mechanism of FD on emissions? Specifically, we measure China’s FD by selecting five original indicators (i.e., the ratio of bank loans to GDP, the ratio of bank loans to savings, the ratio of FDI to GDP, the ratio of stock market value to GDP, the ratio of stock traded value to GDP) and using PCA (principal component analysis) method to construct a comprehensive indicator. We then investigate the evolutionary characteristics of FD-emissions nexus using the Tapio decoupling model. Finally, we decompose the decoupling elasticity between FD and emissions into nine factors, which can be further classified into direct and indirect effects.

We contribute to the current literature with three regards. First, we attach extraordinary importance to the role of FD in China’s emissions using the decoupling model, which is distinctly different from previous studies using the econometric models. The decoupling analysis allows for a continuous observation of the FD-emissions relationship during a specific period, which is consistent with the fact that the impact of FD on emissions is not stationary. Thus, according to the annual estimation of the decoupling elasticity, we can further discuss the dynamic characteristics of the FD-emissions nexus. Second, we embed the LMDI model into the decoupling model to investigate the factors affecting the decoupling relationship. Previous studies concluded that FD helps emissions reduction as it provides market-based
guidance (i.e., stock market development) to promote technological innovation (Wen et al. 2020). They also argued that the FD drives emissions growth, as bank provides credits for firms to increase capital and labor investments (Obobisa 2022). However, previous studies did not elaborate separately the role of various financial means (e.g., stock market, bank loans, and deposits) in the governance of emissions. This may cause controversial results about the impacts of FD on emissions (Zhang 2011, Acheampong et al. 2020). We differ from previous studies as we separately evaluate the impact of different financial indicators on the FD-emissions nexus using the LMDI model. This can help policy makers to formulate effective measures for sustainable financial development. Finally, since technological innovation and production expansion is related with FD and emissions, based on the decoupling analysis, we combined the decomposition method with the Cobb–Douglas (C-D) production function (Dean and Hoeller 1992) to clarify the influencing mechanism of FD on emissions. We decompose the decoupling elasticity of FD and carbon emissions into nine factors, including emission intensity, energy intensity, bank loan intensity on technological progress, stock traded intensity on capital-labor inputs, financial structure, converting efficiency from savings into bank loans, the ratio of bank loans to foreign direct investment, savings, and foreign direct investment. This makes the decomposition results more comprehensive.

The remainder of our paper is structured as follows. The “Methods and data” section describes an introduction of the methods and data. The “Results” section presents the results, and discussions are shown in the “Discussions” section, followed by the conclusions in the “Conclusions and policy implications” section.

**Literature review**

In recent years, several studies have documented the impact of financial development on carbon emissions. For instance, Tamazian et al. (2009), Shahbaz et al. (2013), and Saether et al. (2021) investigated the financial development-emissions nexus and concluded that FD can help reduce emissions by adopting new energy-saving technologies. The same conclusion can be found in Dogan and Turkekul (2016), Lahiani et al. (2021), and Shahbaz et al. (2022). In contrast to these results, some scholars concluded that FD has a positive impact on environmental degradation due to fact that the development of the financial system creates more energy demand (Bui, 2020; Le and Ozturk 2020; Tahir et al. 2021). Ozturk and Acaravci (2013) argued that there is no sufficient evidence to support the impact of FD on emissions. For China, Lahiani (2020) claimed that FD helps lower CO2 emissions in China. Zhao and Yang (2020) found that a percentage increase in provincial FD reduces CO2 emissions in provinces of China except for Fujian, Sichuan, Shaanxi, Xinjiang, Yunnan, and Zhejiang regions.

Theoretically, the impacts of FD on the emissions are inconclusive. First, the impact of FD on the emissions could be positive. Promoting FD could increase access to financial products (e.g., bank loans) for consumers and improve their financial capacities, leading to the increase in the use of carbon-intensive appliances (Dong et al. 2021; Safi et al. 2021; Xu et al. 2022). Meanwhile, the FD provides sufficient funds for companies to expand their production scale (Shahbaz et al. 2012, 2013). These both will unavoidably cause the increase of emissions (Assi et al. 2020; Lahiani et al. 2021). Moreover, as there is credit discrimination among the state-owned commercial banks in China, the traditional manufacturing industry and real estate industry are easier to receive financial resources than green enterprises (Wei and Kong 2017; Hu and Xu 2019). This causes insufficient financial support for the environmentally friendly industry, which is not beneficial for reducing emissions (Chang et al. 2019). Second, the FD could help reduce emissions, as the FD guided by market promotes the technological progress though green finance (Churchill et al. 2019; Wang et al. 2020). Tamazian et al. (2009) and Nasir et al. (2019) argued that the expansion of financial market could reduce carbon emissions by effectively raising funds and investments for green industries. Additionally, green credits in China are the main channel for farmers to obtain external financing, which increases the rural investment in clean energy technologies and further reduces emissions (Chang 2015a, b; Song et al. 2021; Yang and Tang 2021). Third, FD plays an essential role in attracting foreign direct investment (FDI) inflows (Aboky et al. 2019; Wu et al. 2020; Shahzad et al. 2022), and FDI could help invest in the clean energy (Doytch and Narayan 2016; Khan and Ozturk 2021). Thus, the inhibitory effect on emissions can be created by a rise in the FDI that is stimulated by FD (Xu et al. 2021a, b).

In summary, we find that although there have been a growing number of studies on the emissions impact of FD in recent years, most of them focus on national-level problems. Due to the differences in research objects and econometric techniques, studies have not reached consensus on the influence of FD on emissions, and whether they have a positive, negative, or neutral effect. Also, the approaches and effects of FD on emissions varied across contexts. Moreover, most studies used the econometric method to analyze the impact of FD on carbon emissions in China. These studies mainly focused on the average impact of FD on emissions during a given period. No literature investigated the decoupling relationship of FD and emissions. Thus, they ignored the emissions impact of FD at a given time point, which cannot
allow for a continuous observation of the FD-emissions relationship during a specific period.

Methods and data

Based on data from China’s 30 provinces during 2000–2020, we first construct a comprehensive indicator to estimate the FD level using five original financial indicators and PCA analysis. Then, we employ the Tapio decoupling model to explore the FD-emissions nexus. A combination of decoupling model and the LMDI model based on the C-D production function is further employed to investigate the driving factors affecting FD-emissions nexus.

Financial development estimation

It is important to choose suitable indicators to reflect the level of FD in China. Previous studies have used various indicators, such as bank loans, FDI, stock market value, and stock traded value, to reflect the FD level. Referring to Zhao and Yang (2020), we use the five indicators to reflect the FD level in China’s 30 provinces (see Table 1). The FD index in China’s 30 provinces exhibited similar trend except for Hainan and Qinghai (Fig. 1). Specifically, in 2019, the FD of Hainan and Qinghai declined while the FD of other provinces increased.

Decoupling measuring

Referring to Tapio (2005), we estimate the decoupling relationship between FD and emissions (Wang and Zhang 2021) as follows:

$$D = \frac{(C^t - C^0)/C^0}{(FD^t - FD^0)/FD^0} = \frac{\Delta C/C^0}{\Delta FD/FD^0} \tag{1}$$

where D is the decoupling elasticity of the FD from emissions between target year t and base year 0. Tapio defined eight decoupling states: strong decoupling, weak decoupling, expansive decoupling, expansive negative decoupling, strong negative decoupling, weak negative decoupling, recessive coupling, and recessive decoupling (see Fig. 2).

LMDI decomposition model

Equation (1) can be transformed as follows:

$$D = \frac{FD^0}{C^0} \cdot \frac{1}{\Delta FD} \cdot \Delta C = \left(\frac{FD^0}{C^0}\right)^{1/2} \cdot \frac{1}{\Delta FD} \cdot \left(\frac{FD^0}{C^0}\right)^{1/2} \cdot \Delta C \tag{2}$$

Three factors affect the decoupling elasticity of FD from emissions: the ratio of FD to emissions in the base year, the changes of FD, and changes of emissions. We integrated the three factors into two effects using the ratio of FD to emissions in the base year as the influence weight, namely the direct impact of FD on the decoupling elasticity and the indirect impact of FD on emissions. Based on the Kaya identity, the carbon emissions can be further decomposed into various factors. Since the FD plays a role in the promotion of technological innovation and improvement of capital-labor inputs, we combined the C-D production function with the decomposition model as follows:

$$C = \sum \frac{C_i}{E_i} \cdot \frac{E_i}{GDP_i} \cdot \frac{GDP_i}{f(K_i, L_i)} \cdot \frac{f(K_i, L_i)}{STO_i/LOA_i} \cdot \frac{LOA_i}{LOA_{FD_i}} \cdot \frac{LOA_{FD_i}}{DP_i/GDP_i} \cdot \frac{DP_i/GDP_i}{FD_i/GDP_i}$$

$$= \sum CI_i \cdot EI_i \cdot TI_i \cdot KL_i \cdot S_i \cdot M_i \cdot R_i \cdot Q_i \cdot F_i$$

The acronyms are described in Table 2.

We regard CI, EI, TI, and KL as intensity effects. We regard S, M, R, Q, and F as structure effects, because these indicators reflect the composition of FD. In the Kaya identity, we employ the form of the C-D production function (Wang et al. 2019):

$$Y = A \cdot f(K, L) = A \cdot K^\alpha \cdot L^\beta \tag{4}$$

where A is technological progress, Y is economic output, K is capital stock, and L is annual average employed persons. α and β are elasticity coefficient of capital and labor, respectively. We transform above function in log scale as follows:

### Table 1 Indicator summary

| Indicator                        | Meaning                                      | Source                    |
|---------------------------------|----------------------------------------------|---------------------------|
| Ratio of bank loans to GDP      | Scale of financial intermediation development| Provincial Statistical Yearbook |
| Ratio of bank loans to savings  | Efficiency of transforming savings into bank loans | Provincial Statistical Yearbook |
| Ratio of FDI to GDP             | Scale of FDI                                 | Provincial Statistical Yearbook |
| Ratio of stock market value to GDP | Scale of stock markets                        | Wind database             |
| Ratio of stock traded value to GDP | Efficiency of stock markets                  | Wind database             |
Since the output is heterogeneous across provinces, the elasticity coefficients of capital and labor are different. Thus, a regression equation for each province can be obtained based on Eq. (5) as follows:

\[ \ln Y = \ln A + \alpha \ln K + \beta \ln L \]  

(5)

where \( c \) is an intercept term and \( \epsilon \) is an error term. After estimating the parameter for capital and labor using the provincial data, we embed the elasticity coefficients of capital and labor into the Kaya identity. Additionally, we cannot obtain official data on the capital input in China. Therefore, we use the perpetual inventory method to estimate the capital stock as follows:

\[ K_t = (1 - d) \cdot K_{t-1} + I_t, \quad t = 2000, \ldots, 2019 \]  

(7)

where \( K \) is the capital stock in year \( t \), \( I \) is the investment, and \( d \) is the capital depreciation rate, which we assume to be 10%. The capital stock in the starting year of 2000 is from Zhang et al. (2004).

In order to analyze the impact of these driving factors on emissions from 0 to \( t \), we apply the LMDI decomposition method (Ang et al. 2004) as follows:

\[ \Delta C = C - C^0 = \Delta C_{EI} + \Delta C_{TI} + \Delta C_{KI} + \Delta C_S + \Delta C_M + \Delta C_R + \Delta C_Q + \Delta C_F \]  

(8)

where \( \Delta C_{EI}, \Delta C_{TI}, \Delta C_{KI}, \Delta C_S, \Delta C_M, \Delta C_R, \Delta C_Q, \) and \( \Delta C_F \) are the impacts of emission intensity, energy intensity, bank loan intensity on technological progress, stock traded intensity on capital-labor inputs, financial structure, converting efficiency from savings into bank loans, the ratio of bank loans to foreign direct investment, savings, and foreign direct investment, respectively. Referring to Ang and Zhang (2000), Xu and Ang (2013), and Ang and Goh (2019), these impacts are estimated based on the equations in Table 3.
Then, we embed the Eq. (8) into Eq. (1) as follows:

\[
D = \left( \frac{FD^0}{C^0} \right)^{1/2} \cdot \frac{1}{\Delta FD} \left( \frac{FD^0}{C^0} \right)^{1/2} \cdot (\Delta C + \Delta C_{CI} + \Delta C_{EI} + \Delta C_{TI} + \Delta C_{KI} + \Delta C_{S} + \Delta C_{M} + \Delta C_{R} + \Delta C_{Q} + \Delta C_{F})
\]  

(9)

We regard \( \left( \frac{FD^0}{C^0} \right)^{1/2} \cdot \frac{1}{\Delta FD} \) as direct effects, and we decompose the indirect effects into nine factors as shown in Eq. (8). These impacts are estimated based on the equations in Table 4. Additionally, we transformed Eq. (1) as follows:
$$D = \frac{FD}{C} \cdot \left( \frac{1}{\Delta FD} \cdot (\Delta C_2 + \Delta C_3 + \Delta C_4 + \Delta C_5 + \Delta C_6 + \Delta C_7 + \Delta C_8 + \Delta C_9 + \Delta C_{10}) \right)$$

$$\frac{\Delta C_1}{\Delta FD} + \frac{\Delta C_2}{\Delta FD} + \frac{\Delta C_3}{\Delta FD} + \frac{\Delta C_4}{\Delta FD} + \frac{\Delta C_5}{\Delta FD} + \frac{\Delta C_6}{\Delta FD} + \frac{\Delta C_7}{\Delta FD} + \frac{\Delta C_8}{\Delta FD} + \frac{\Delta C_9}{\Delta FD} + \frac{\Delta C_{10}}{\Delta FD}$$

We use $$\frac{1}{\Delta C_1}, \frac{1}{\Delta C_2}, \frac{1}{\Delta C_3}, \frac{1}{\Delta C_4}, \frac{1}{\Delta C_5}, \frac{1}{\Delta C_6}, \frac{1}{\Delta C_7}, \frac{1}{\Delta C_8}, \frac{1}{\Delta C_9}, \frac{1}{\Delta C_{10}}$$ to reflect the coefficients related with the impacts of the decoupling elasticity of FD and energy intensity (DEI$_{EI,FD}$), decoupling elasticity of FD and energy intensity (DEI$_{EI,FD}$), decoupling elasticity of FD and energy consumption on technological progress (DEI$_{EI,F}$), decoupling elasticity of FD and energy consumption on technological progress (DEI$_{EI,F}$), decoupling elasticity of FD and energy consumption on technological progress (DEI$_{EI,F}$), and decoupling elasticity of FD and energy consumption on technological progress (DEI$_{EI,F}$).

$$C_{i,0} = E_{i,0}^0$$

$$E_{i,0} = \frac{C_{i,0}}{E_{i,0}^0} \cdot GDP_{i,0}$$

$$T_{i,0} = \frac{C_{i,0}}{GDP_{i,0}^0} \cdot F_{i,0}(K, H) \cdot STO_{i,0}^0 / GDP_{i,0}$$

$$K_{i,0} = \frac{C_{i,0}}{F_{i,0}(K, H)} \cdot LOA_{i,0}^0 / GDP_{i,0} \cdot 11 - 4$$

$$S_{i,0} = \frac{C_{i,0}}{STO_{i,0}^0 / LOA_{i,0}^0}$$

$$M_{i,0} = \frac{C_{i,0}}{LOA_{i,0}^0 / GDP_{i,0}}$$

$$R_{i,0} = \frac{C_{i,0}}{LOA_{i,0}^0 / FD_{i,0}}$$

$$Q_{i,0} = \frac{C_{i,0}}{FD_{i,0} / GDP_{i,0}}$$

$$F_{i,0} = \frac{C_{i,0}}{FD_{i,0} / GDP_{i,0}}$$

We regard the decoupling elasticity of FD and emissions as the linear combination of nine decoupling elasticity factors. These factors are estimated based on the equations in Table 5.

**Data sources**

The data on bank loans, savings, FDI, GDP, annual average employed persons, and investment scale are from the Provincial Statistical Yearbooks. The data on carbon emissions and energy consumption are from CEADs. The data on stock market value and stock traded value are from WIND database. We convert GDP and investment into real inflation-adjusted data (base year: 2000) and using the price index from the Provincial Statistical Yearbooks. The open international market after joining the WTO in 2001 stimulated the huge development of finance in China. Moreover, the latest CEADs data on provincial carbon emissions are from 2019. Therefore, our study covers the period of 2000–2019. Due to limited data, we exclude Tibet, Hong Kong, Macao, and Taiwan.

**Results**

**Decoupling analysis**

The carbon emissions in China kept increase over the period 1997–2019 except for 2006. Specifically, China’s carbon emissions grew by 8034 million tons (Mt) with an annual growth rate of 7.5% year$^{-1}$ (Fig. 3a). The growth rates of emissions reached 17% year$^{-1}$ and 18% year$^{-1}$ in 2003 and 2005, respectively, which were the highest growth rates during 1997–2019. The finance experienced a notably fluctuation and the FD index rose from 0.8 to 1.3 from 1997 to 2019. The FD index peaked at 1.6 in 2007 with a 44% year$^{-1}$ decline in 2008 due to the impact of global financial crisis and a temporary rebound of 54.1% year$^{-1}$ in 2009. After 2009, the FD index declined at 8.1% year$^{-1}$ until 2013 and then increased at 5.2% year$^{-1}$, peaking at 2.2 in 2015. During 2015–2019, the FD index decreased at 12.2% year$^{-1}$. The national decoupling index was negative during 2000–2005 except for 2003 (Fig. 3b), which means the inhibiting factors did not play significant roles in the emissions mitigation process and turned into contributors to carbon emissions increase together with FD. The national decoupling index was expansive negative decoupling in 2003, which indicates that the carbon reduction effect from the inhibiting factors was significantly smaller than the driving effect contributed by FD. After 2005, the weak decoupling happened in some years such as 2006–2007, 2009, and 2013–2015. This means that the FD and carbon emissions increase simultaneously.

The strong negative decoupling was the most frequently occurring category in 30 provinces (Fig. 3c). For example,
affecting by the 2008 global financial crisis, except for Guizhou and Beijing, all provinces experienced strong negative decoupling. The weak decoupling occurred in waves, where some provinces saw weak decoupling in several years followed by periods of strong negative decoupling followed again by temporary weak decoupling. For instance, after the 2008 global financial crisis, in 2009, most provinces showed weak decoupling except for Zhejiang, Shaanxi, Henan, and Gansu. This means that although provincial governments tried to reduce emissions by stimulating \(FD\) after financial crisis, the \(FD\) did not mitigate emissions effectively. This is because that under the performance assessment of \(FD\), the financial market did not pay enough intention to control the increase in emissions. Moreover, it is possible that these provinces did not arrange a stable financial share to support the use of clean energy technologies. During 2013–2019, the strong decoupling occurred more frequently than during the period of 2000–2012. Especially during the period of 2013–2015, 42% of provinces experienced the strong decoupling. This means that the \(FD\) in these provinces promoted the decrease in emissions. The progress realized by these provinces is because that the massive \(FD\) of China occurred during this period, resulting in additional financial capacity to support for advanced technologies. In 2019, 40% of provinces showed expansive negative decoupling; however, there was no obvious impact of economic development on the decoupling state. For example, for developed provinces, Jiangsu and Tianjin showed expansive decoupling, while Beijing and Zhejiang exhibited strong decoupling. Overall, \(FD\) did not develop a stable decoupling relationship with

![Fig. 3 Decoupling of \(FD\) and carbon emissions for the period 2000–2019. a \(FD\) and carbon emissions. b The national decoupling index. c Decoupling states of 30 provinces. Note: In b, the year \(X\) represents the period from year \(X−1\) to year \(X\). In c, numbers show the different decoupling states: 0, no data; 1, strong decoupling; 2, weak decoupling; 3, expansive coupling; 4, expansive negative decoupling; 5, strong negative decoupling; 6, weak recessive decoupling; 7, recessive coupling; 8, recessive decoupling]
carbon emissions, as the FD was unstable and their impacts on emissions were not fixed. However, when the finance develops at a very high level (e.g., during the period of 2013–2015), the FD had spare capacities to promote the reduction in the carbon emissions.

**Driving factors of decoupling state**

When the decoupling state presented weak decoupling, the indirect and direct effects reflected the same direction of changes. When the decoupling state was strong negative decoupling, the direct and indirect impacts reflected reversed changes (Fig. 4a). This is because the direct impact was affected by the changes in the FD, while the indirect impact relied on the change in emissions which are driven by other factors. Once important events (e.g., global financial crisis) brought shocks for the FD, the strong negative decoupling happened (i.e., the year of 2008) due to a negative direct effect and a positive indirect effect. With the stable economic development, the weak decoupling occurred in several years (e.g., 2013–2015) due to a continuous growth in the FD and emissions. In 2016, although relevant driving factors brought negative indirect effect, the FD presented a positive direct effect, resulting in a weak negative decoupling.

The energy intensity restrained the increase in emissions in most years expect for 2003–2005, as China’s clean energy consumption fast increased and the dominant share of coal in the energy consumption decreased. Thus, to obtain strong decoupling of FD and emissions, it is important to reduce the energy intensity by substituting coal with clean energy (Fig. 4b). The financial structure played the most significant role in controlling the growth in emissions during most years with strong negative decoupling. This reflects the positive role of bank-based financial structure in the emission mitigation in the face of financial crisis. Thus, the bank-based financial structure can allocate their financial resources to advanced energy-efficient technologies and environmental protection projects during crisis periods. However, the financial structure had positive impact on the increase in the emissions when the weak decoupling was achieved. This

Fig. 4 Driving factors of decoupling between FD and carbon emissions in China during 2000–2019. a Direct effect and indirect effects. b Decomposition of indirect effects. Note: The year X represents the period from year X – 1 to year X
means that the impact of financial structure on emissions was a dynamic evolution trend with the change of FD. Once the weak decoupling happened, the effect of stock traded intensity on technological progress played the major role in mitigating emissions. This means that the stock market prefers to provide financial sources for the environmentally friendly technologies when the FD increased. In contrast, the stock traded intensity on technological progress limited the emission reduction when the FD decreased. Thus, with fast financial development, higher levels of stock market development are conducive to the reduction of emissions by promoting clean technologies.

During 2000–2012, the impact of FDI on emissions was positive except for the years of 2001, 2004, and 2008–2009, while during 2013–2019, the FDI reduced emissions. This is because that in the initial period of financial market development, the FDI stimulates economic activities and prefers to provide funds to polluting industries, which degrade the environment. With the optimization of China’s financial market and policy invention, the FDI gradually switches toward environmentally friendly industries, which promotes the application of clean energy technologies and reduces emissions. The impact of bank loan intensity on capital-labor inputs on emissions was positive except for 2009. This reflects the key role of bank loans in increasing capital-labor inputs. Since the capital-labor inputs means the production expansion, which increases emissions, the unlimited expansion of bank loans would prevent the achievement of strong decoupling.

Except for the years of 2003–2004, the decoupling elasticity of FD from stock traded intensity on the technological progress exhibited a negative effect on the decoupling elasticity of FD from emissions. This means that the development of stock market helps the realization of an ideal decoupling state of FD and emissions through the technological advancement. The decoupling elasticity of FD and financial structure had a positive effect on the decoupling elasticity of FD from emissions. This means when governments develop the stock market to promote the technological improvement, they need to consider the share of stock market in the overall financial market, because complete stock-dominated financial structure is driven by the profitable production, which might lead to the outdated production and related emissions increases. Thus, governments need to construct an appropriate financial structure such that the decoupling relationship of FD and emissions can be transformed into an ideal state. The impacts of the decoupling elasticities of FD from other factors are not stable. When the decoupling state of FD and emissions was strong negative decoupling, the decoupling elasticity of FD from energy intensity drove the increase in the decoupling elasticity of FD from emissions. When the decoupling state of FD and emissions was weak decoupling, the decoupling elasticity of FD from energy intensity contributed the decrease in the decoupling elasticity of FD from emissions. Thus, the decoupling elasticity of FD from energy intensity was the important factor driving the optimal decoupling state of FD and emissions (Fig. 5).

Discussions

Dynamic characteristics of the decoupling state

Theoretically, the strong decoupling between FD and emissions, which reflects FD promotes the emissions reduction, is encouraged, because we hope that financial instruments can play a vital role in mitigating climate change by satisfying the financial demand for low-carbon projects. However, we found that the decoupling state between the two is not a stable and the strong decoupling is not easy to obtain. Unlike previous studies using econometric models, which concluded that the relationship between FD and emissions is positive or negative within a given sample, we argue that the decoupling state of FD and emissions experienced changes in waves, reflecting dynamic characteristics due to the volatility of FD itself. During the financial crisis phase, the FD could not simulate effective source allocation to promote technological innovation. Thus, the FD could not play a role in reducing emissions, and the strong negative decoupling appears. To ensure that the finance does not collapse, governments must provide stimulus packages and other bailout plans, thereby leading to the waking up of FD. However, the increased FD cannot immediately lead to significant emissions reductions, as the financial resource allocation often seeks to high profits and thereby prefers to support traditional industrial sectors due to the constraint of initial market conditions (Yin and Xu 2022). If increased FD leads to an increase in emissions, the decoupling state of FD and emissions shifts from strong negative decoupling to coupling/weak decoupling. Thus, a low level of FD could restrict the coordinated development between finance and environment. The strong decoupling could be realized only when the FD reaches a high level. Because the requirements of sustainable economic development must pressurize FD to effectively allocate financial resources. Moreover, a higher level of FD would consider low-carbon and sustainable development as the fundamental task, because investors and financial institutions have enough motivation to access the low-carbon projects based on prosperous market environment (Hunjra et al. 2022). When the FD gradually distributes more financial resources to environmentally friendly projects, FD can promote emissions reduction. However, we find that even if during the fast development period of finance (i.e., 2013–2015), there are more than half of provinces could not
achieve strong decoupling. This reflects that the inhibiting impact of green finance on the emissions mitigation is not optimistic in China. Thus, it is urgent to introduce market-oriented approaches and preferential policies to the green finance field for a high-quality FD.

A comparison with previous studies

Several studies support the finding that emissions decreased with the stock market development, as the stock market expansion encouraged the use of clean energy (Zeqiraj et al. 2020; Sharma et al. 2021). Other studies observed the positive impact of stock market development on the increase of emissions as the development of stock market expand the scale of production and intensified energy consumption (Chang 2015a, b). These mixed results are due to the difference in the research sample in terms of periods and objectives. We found that the stock market development reduced emissions by promoting technological improvement when FD presented an upward trend. However, when FD entered crisis period, the stock market development increased emissions. This can be explained by Chang et al. (2020) study, which argued that during financial crisis, investors were more sensitive to asset losses, and were likely to exhibit panic in the stock market, hence decreased the investment in the advanced technologies. In our study, the impact of financial structure on emissions presented a dynamic trend, which is similar with the observation of Wen et al. (2021) that the driving effect of financial structure on emission reduction exhibited a U-shaped relationship. We found that bank loans increased emissions as they provide financial support for the growth of capital-labor inputs, which is consistent with previous studies (Zafar et al. 2019; Yao et al. 2021). Moreover, some studies identified the FDI as an important inhibiting factor of reducing emissions. For example, the FDI decreased emissions in less-developed countries (Zeng and Eastin 2012), ASEAN-5 countries (Zhu et al. 2016), and OECD countries (Marques and Caetano 2021). In contrast, Liu et al. (2021b) confirmed that FDI positively affected China’s emissions. However, they argued that the positive impact of FDI on emissions was smaller in provinces with more innovation. This indicates that the emissions impact of FDI is dynamic with the increase of innovation level, which can partly explain our results.

Conclusions and policy implications

Conclusions

With the rapid economic development in China, carbon emissions have brought severe environmental problems.
Systematically observing the FD-emissions nexus can help us to achieve sustainable development goals. We explored the decoupling relationship of FD from carbon emissions during 2000–2019. Then, we used the decomposition method to analyze the nine drivers of decoupling elasticity of FD from carbon emissions. It is possible for our study to play an important role in shaping future practice and formulating policies.

We found that China experienced weak decoupling and strong negative decoupling in most years of 2000–2019. Only the finance develops at a very high level; the FD had spare capacities to promote the reduction in the carbon emissions. For example, several developed provinces (e.g., Tianjin, Zhejiang, Guangdong) realized strong decoupling after 2012. The reduction in the energy intensity and the increase of FDI promoted the decoupling of FD from carbon emissions. With the fast FD, the development of stock market contributed to the decoupling of FD from carbon emissions through technological improvement, while the bank loans delayed the decoupling of FD from carbon emissions through the expansion of capital-labor inputs. Moreover, during the financial recession period, the bank-based financial structure played an important role in reducing carbon emissions. Once financial crisis is overcome, developing a market-based financial structure promoted the decoupling of FD from carbon emissions.

Policy implications

The objective of FD-emissions decoupling is to stimulate the role of FD in mitigating emissions, which offers opportunities for the sustainable development. We found that the energy intensity reduction was the key to mitigate emissions. Thus, low-carbon development policies are required to promote the reduction in the energy intensity, which relies on the reshape of low-carbon energy system and energy-related innovation. Moreover, FDI had a mitigating effect on emissions; thus, China needs to promote the development of FDI by relaxing the FDI restriction. Meanwhile, FDI policies need to be redesigned to encourage industrial sectors to fully utilize the FDI capacity, such that the attraction for clean technologies can increase to solidify sustainable development goals.

However, China’s path towards the FD-emissions decoupling is accompanied with challenges and uncertainties (e.g., the impact of financial recession with the COVID-19 spread) (Wang and Su, 2020a, b; Mensi et al. 2022). One way of addressing such issue is to analyze the impact of financial structure on emissions such that FD can help reduce emissions by effective resource allocation. We found that when we are face with the financial recession, the bank-based financial market slow down emissions by the effective allocation of financial resources. This is because with financial crisis, the investment in clean technologies prefers to avoid financial risks. The activities of banking sector can help investors solve the problem of asymmetric information based on their knowledge, such that financial funds can be redistributed from energy-intensive projects to low-carbon technologies. This indicates that a well-functioning bank-based financial market could support green investment, hence decreasing the emissions during the financial crisis. Thus, developing a bank-based financial market might promote the emissions reduction in terms of COVID-19 outbreak. Moreover, although a bank-based financial market is a way to reduce emissions for current situation, the unreasonable increase of bank loans might lead to the increase in the emissions due to the exorbitant expansion of production. Thus, keeping a reasonable share of bank loans in the overall financial market by setting a high limit for bank loans is necessary.

China’s government is now proposing economic recovery plans for COVID-19 pandemic, which will bring recovery of financial market (IMF, 2020; Wang et al., 2021a, b). We found that the stock market development reduced emissions by promoting technological improvement when FD increased. Thus, the governments should realize the potentiality of the stock market development in the emissions mitigation during the post-COVID period. Once financial crisis is overcome, the policy makers need to develop a market-based financial structure considering market environment changes, which will provide funds for clean energy projects. Meanwhile, governments should implement sustainable policies and provide investment incentives to encourage all the listed companies to utilize low-carbon technologies in their production processes.

Future work

We provide evidence of the decoupling relationship between emissions and FD to draw environmental implications considering possible FD pathway. As an avenue for further research, the general future picture can be complemented by understanding the changes of factors that impact the decoupling relationship. Such work, combined with the specific changes of factors, would provide solid references for policy makings.
## Appendix

### Tables 3, 4 and 5

**Table 3** Equations for nine driving factors

| Decomposed target | Driving factors | Calculation equations | Attributes |
|--------------------|-----------------|-----------------------|------------|
| \( \Delta C \)     | \( \Delta C_{CI} \) | \( \sum_r L(C_r, C_0^i) \ln \left( \frac{C_r}{C_0^i} \right) \) | Intensity effect |
| \( \Delta C_{CI} \) | \( \sum_r L(C_r, C_0^i) \ln \left( \frac{C_r}{C_0^i} \right) \) | Structure effect |
| \( \Delta C_{EI} \) | \( \sum_r L(C_r, C_0^i) \ln \left( \frac{C_r}{C_0^i} \right) \) | |
| \( \Delta C_{TI} \) | \( \sum_r L(C_r, C_0^i) \ln \left( \frac{C_r}{C_0^i} \right) \) | |
| \( \Delta C_{KI} \) | \( \sum_r L(C_r, C_0^i) \ln \left( \frac{C_r}{C_0^i} \right) \) | |
| \( \Delta C_S \)   | \( \sum_r L(C_r, C_0^i) \ln \left( \frac{S_r}{S_0^i} \right) \) | |
| \( \Delta C_M \)   | \( \sum_r L(C_r, C_0^i) \ln \left( \frac{M_r}{M_0^i} \right) \) | |
| \( \Delta C_R \)   | \( \sum_r L(C_r, C_0^i) \ln \left( \frac{R_r}{R_0^i} \right) \) | |
| \( \Delta C_Q \)   | \( \sum_r L(C_r, C_0^i) \ln \left( \frac{Q_r}{Q_0^i} \right) \) | |
| \( \Delta C_F \)   | \( \sum_r L(C_r, C_0^i) \ln \left( \frac{F_r}{F_0^i} \right) \) | |

Note: \( L(C_r, C_0^i) = \frac{C_r - C_0^i}{\ln(C_r/C_0^i)} \) is logarithmic weight function

**Table 4** Equations for factors affecting the changes in the decoupling relationship

| Decomposed target | Driving forces | Calculation equations | Perspective |
|-------------------|---------------|-----------------------|-------------|
| \( D_{C, AGE} \)  | \( FD \)       | \( (FD^0 / C^0)^{1/2} / \Delta FD \) | Direct effect |
| \( C_I \)         | \( FD \)       | \( (FD^0 / C^0)^{1/2} \sum_r L(C_r, C_0^i) \ln \left( \frac{C_r}{C_0^i} \right) \) | Indirect effect |
| \( E_I \)         | \( FD \)       | \( (FD^0 / C^0)^{1/2} \sum_r L(C_r, C_0^i) \ln \left( \frac{E_r}{E_0^i} \right) \) | |
| \( T_I \)         | \( FD \)       | \( (FD^0 / C^0)^{1/2} \sum_r L(C_r, C_0^i) \ln \left( \frac{T_r}{T_0^i} \right) \) | |
| \( F_I \)         | \( FD \)       | \( (FD^0 / C^0)^{1/2} \sum_r L(C_r, C_0^i) \ln \left( \frac{F_r}{F_0^i} \right) \) | |
| \( S \)           | \( FD \)       | \( (FD^0 / C^0)^{1/2} \sum_r L(C_r, C_0^i) \ln \left( \frac{S_r}{S_0^i} \right) \) | |
| \( M \)           | \( FD \)       | \( (FD^0 / C^0)^{1/2} \sum_r L(C_r, C_0^i) \ln \left( \frac{M_r}{M_0^i} \right) \) | |
| \( R \)           | \( FD \)       | \( (FD^0 / C^0)^{1/2} \sum_r L(C_r, C_0^i) \ln \left( \frac{R_r}{R_0^i} \right) \) | |
| \( Q \)           | \( FD \)       | \( (FD^0 / C^0)^{1/2} \sum_r L(C_r, C_0^i) \ln \left( \frac{Q_r}{Q_0^i} \right) \) | |
| \( F \)           | \( FD \)       | \( (FD^0 / C^0)^{1/2} \sum_r L(C_r, C_0^i) \ln \left( \frac{F_r}{F_0^i} \right) \) | |

Note: \( L(C_r, C_0^i) = \frac{C_r - C_0^i}{\ln(C_r/C_0^i)} \) is logarithmic weight function

**Table 5** Equations for factors affecting the changes in the decoupling relationship

| Decomposed target | Driving forces | Calculation equations |
|-------------------|---------------|-----------------------|
| \( \Delta D_{C, AGE} \) | \( \frac{1}{C_0^i} \frac{DFD}{\Delta FD} \) | \( \sum_r \frac{L(C_r, C_0^i) \ln \left( C_r/C_0^i \right)}{C_0^i} \) |
| \( \Delta D_{EI, FD} \) | \( \frac{1}{E_0^i} \frac{DFD}{\Delta FD} \) | \( \sum_r \frac{L(C_r, C_0^i) \ln \left( E_r/E_0^i \right)}{E_0^i} \) |
| \( \Delta D_{TI, FD} \) | \( \frac{1}{T_0^i} \frac{DFD}{\Delta FD} \) | \( \sum_r \frac{L(C_r, C_0^i) \ln \left( T_r/T_0^i \right)}{T_0^i} \) |
| \( \Delta D_{KI, FD} \) | \( \frac{1}{K_0^i} \frac{DFD}{\Delta FD} \) | \( \sum_r \frac{L(C_r, C_0^i) \ln \left( K_r/K_0^i \right)}{K_0^i} \) |
| \( \Delta D_{S, FD} \) | \( \frac{1}{S_0^i} \frac{DFD}{\Delta FD} \) | \( \sum_r \frac{L(C_r, C_0^i) \ln \left( S_r/S_0^i \right)}{S_0^i} \) |
| \( \Delta D_{M, FD} \) | \( \frac{1}{M_0^i} \frac{DFD}{\Delta FD} \) | \( \sum_r \frac{L(C_r, C_0^i) \ln \left( M_r/M_0^i \right)}{M_0^i} \) |
| \( \Delta D_{R, FD} \) | \( \frac{1}{R_0^i} \frac{DFD}{\Delta FD} \) | \( \sum_r \frac{L(C_r, C_0^i) \ln \left( R_r/R_0^i \right)}{R_0^i} \) |
| \( \Delta D_{Q, FD} \) | \( \frac{1}{Q_0^i} \frac{DFD}{\Delta FD} \) | \( \sum_r \frac{L(C_r, C_0^i) \ln \left( Q_r/Q_0^i \right)}{Q_0^i} \) |
| \( \Delta D_{F, FD} \) | \( \frac{1}{F_0^i} \frac{DFD}{\Delta FD} \) | \( \sum_r \frac{L(C_r, C_0^i) \ln \left( F_r/F_0^i \right)}{F_0^i} \) |
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Rong Yuan: conceptualization, data curation, formal analysis, methodology, software, investigation, writing—original draft.
Haoyun Liao: conceptualization, methodology, writing—review, editing, supervision.
Yiyun Ge: data curation, methodology.

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Data availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request. All data generated or analyzed during this study are included in this published article.

Declarations

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