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Effects of China's land-intensive use on carbon emission reduction: A new perspective of industrial structure upgrading

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The rapid and disorderly expansion of urban construction land has resulted in massive carbon emissions, intensifying the contradiction between land use and low-carbon development. As an essential tool to increase land use efficiency, whether land-intensive use can balance economic and environmental benefits has emerged as a topical issue. This paper investigates the influence of land-intensive use on carbon emissions and its role mechanism under the perspective of industrial structure upgrading by using a two-way fixed-effects model with provincial panel data from 2008 to 2020 in China. The statistical results reveal that land-intensive use not only reduces carbon emissions but also boosts carbon emission efficiency, which achieves carbon emission reduction from both quantity and quality aspects. The carbon emission reduction effect of land-intensive use is mainly manifested in energy, capital, science, and education factors of land-intensive use. The carbon emission reduction benefits obtained through land-intensive use are more noticeable in regions with higher economic development levels. Land-intensive utilization is mainly responsible for carbon emission reduction through promoting industrial structure advanced quality. Our findings suggest that policy makers shall expedite land intensive use development, appropriately synchronize land use levels across regions, and adequately leverage the role mechanisms of advanced industrial structure as a potent measure to promote carbon emission reduction.

KEYWORDS

carbon emissions, carbon emission efficiency, land intensive use, industrial structure upgrading, China

1 Introduction

Since the industrial revolution, steam power and electricity have been widely used in human society to contribute significantly to the world economy advancement (Ren et al., 2021; Liu et al., 2022). Meanwhile, rapid economic development has emitted massive amounts of greenhouse gases (GHG), mainly carbon dioxide, which has generated a severe global warming problem (Cao et al., 2022; Ling et al., 2022). Since the first World Climate Conference held in Geneva, this matter has received increasing attention from the international community (Agrawala, 1998). Although countries around the world have reached many agreements on reducing carbon emissions to combat climate warming, such as the Paris Climate Agreement reached in 2015, the implementation of the agreements, particularly carbon reduction mandates to curb the global greenhouse effect, is still a challenge (Hao et al., 2022; Sun et al., 2022). The provisional report on global climate in 2021 released by the World Meteorological Organization reveals that the global climate problem is not promising to improve (Irfan et al., 2022).

The data indicate that GHG concentrations peaked at a new record high in 2020, which is expected to set another record in 2021, reflecting the fact that the warming problem is not being effectively addressed (Wu et al., 2021; Razzaq et al., 2022). Compared to the years 1850–1900, global temperatures will be 1.09°C higher from January to September in 2021, on average, which is currently ranked by the World Meteorological Organization as one of the warmest years on record globally (Ribes et al., 2021; Scafetta, 2021). The above facts demonstrate that it is urgent to find breakthrough solutions to speed emission reduction of economic activities to control the increasingly severe climate warming problem (Liu et al., 2023). As a significant living space for human economic activities, the participation of the land factor is indispensable for most economic activities. Studies, such as the Global Carbon Project (GCP), which reveals that one of the primary drivers of global warming is carbon emissions from land use change, imply that land use change is a significant role in influencing global climate challenges (Wang et al., 2020). It is no coincidence that the World Resources Organization and carbon cycle experts have found that nearly 1/3 of all GHG are caused by carbon emissions from land use change (Yi et al., 2011; Meyfroidt et al., 2013). How reasonable land use is an essential part of responding to the global warming problem. The Regulations on the Economic and Intensive Use of Land issued by the Chinese government in 2014 indicate that land-intensive use that is concentrated on a small area improves productivity and brings about sensible land use. (Liu et al., 2014; Dong et al., 2020). Land-intensive use is a social and economic activity that maximizes economic returns per unit of land by integrating labor, capital, technology, and other factors per unit to achieve efficient resource utilization and sustainable economic development Wang et al., (2021a). Therefore, the land-intensive use level has an important influence on carbon emission reduction.

It is estimated that optimal land use contributes a critical 27.6% to China's reaching a 40%–45% carbon reduction per unit of GDP by 2020 below 2005 levels (Yang et al., 2022a). Simultaneously, land use changes are often associated with changes in industrial structure (Deslatte et al., 2022; Zhang and Wu, 2022). Land-intensive use development compels high-energy consuming enterprises to migrate, enabling more scope for more multi-phase adapted low-energy consuming enterprises, which causes changes in industrial structure and shock low-carbon economic development (Wang et al., 2020). China is actively undertaking the corresponding obligations to mitigate the global warming issue and states that efforts to advance carbon peaking and carbon-neutral actions should be made reliably (Gao et al., 2022). Although action plans are being developed to ensure that carbon emission goals are met by 2030, it is also imperative to maintain efficiency in attaining this dual carbon target, respectively. In this context, can land-intensive use improvement contribute to carbon emission reduction? If so, what role does industrial structure upgrading plays in this process? Is there any variation in the effect that the impact of land-intensive use on carbon emission reduction under various economic development levels? Which factors of labor intensity, energy consumption intensity, capital expenditure intensity, and science and education investment intensity in drive this positive effect? The conceptual and applied consequences of the these issues are vital to evaluate in light of China's goal of reaching its carbon peak by the year 2030.

This paper develops the current investigation from the following aspects. First, this paper considers the effect of land intensive use on carbon emission reduction from both "quantitative" and "qualitative" dimensions, bridging the boundary between rational utilization of land resources and climate governance. Second, this paper also explores the impact of land intensive use on carbon emission reduction from the energy, capital and science and education factors of land intensive use in more detail. Thirdly, this paper mines the influence mechanism of land-intensive use in achieving carbon emission reduction based on industrial structure advancement and industrial structure rationalization. Finally, the heterogeneous influence of land-intensive use on carbon emission reduction is further quantified considering regional development imbalance and economic level differences.

2 Literature review

2.1 Research on land use and carbon emissions

Land use change has emerged as one of the critical influences on carbon emissions change (Houghton and Hackler, 1999; Yang et al., 2020; Yang and Li, 2022). Scholars have discussed the land use and carbon emissions nexus extensively, yet there is no unanimous opinion on the topic. The perspectives discussed by scholars are very different. And can be divided into the following aspects. First, land use intensity and carbon emissions nexus was tested. It has been pointed out that land use intensity is an essential influencing factor in carbon emission changes (Beetz et al., 2013). Zhu et al. (2022) studied Shandong as an example and pointed out that there was variability land use intensity and carbon emissions nexus. Chuai et al. (2019) found that carbon emissions increase with a continuous increase in land use intensity in Nanjing city, which is consistent with the results of Zhang and Wu (2022) were similar.

Second, some scholars have tested the nexus between land use structure and carbon emissions. Some scholars point out that the volume of carbon emissions from land being used development is more substantial. Wang et al., (2021b). For example, Zhang et al. (2018) argued that the ecological land in Yingkou city would gradually decrease, and the agricultural land and urban construction land would gradually increase over time, which would affect the respiration of the decomposition rate of apoplastic matter by changing the climate of the city, and thus affect the carbon emissions of the city. Jin et al. (2019) found that by simulating the change in land structure in Shandong Province in 2025, the construction land in Shandong Province would increase significantly compared to 2015, while other types of land use would show a decreasing trend. Deng and Gibson (2019) confirmed that the greenhouse effect is more pronounced in areas covered by built-up areas. Zhu et al. (2019) used Anhui Province and Zhejiang Province, respectively, to reach similar conclusions. Further, examining urban agglomerations, scholars found that carbon emissions from built-up areas were higher (Cui et al., 2019; Wang et al., (2021a) and were mainly concentrated in urbanized areas with more rapid economic development. In addition, Chen et al. (2020) found that the Chengdu-Chongqing urban agglomeration in China has the highest carbon emissions from construction land as proportion of overall carbon emissions, while Chengdu and Chongqing have higher carbon emissions.

Third, the nexus between land use efficiency and carbon emissions has also been fully explored. Yang et al. (2020), For example, showed that land use efficiency and carbon emissions are closely related. Zhou et al. (2021) opined that cities' land use efficiency and carbon emissions mainly show three characteristics: high urbanization-low emissions, medium urbanization-high emissions, and low urbanization-low emissions. In addition, Zhang et al. (2018) revealed that high-quality land use reduces carbon emissions.

Fourth, some scholars have investigated the nexus between land-intensive use and carbon emissions. Ricardo first proposed the concept of land-intensive use for agricultural land-intensive use. Moreover, the concept of land-intensive use was extended to urban land-intensive use. The existing literature on land-intensive use and carbon emission effect mainly focuses on cities and urban agglomerations. Wang et al. (2019) concluded that there is a relationship between high input, high output, and high energy consumption in land use, but urban-intensive land use will be beneficial to achieve low carbon development. However, Zhu et al. (2022) came to a different conclusion, stating that at this stage, the increase in intensive land use in China's province will significantly and negatively affect carbon emissions while the spillover effect from neighboring provinces is not significant.

2.2 Research on the role mechanism of land use affecting carbon emission

As for how land use affects carbon emissions, scholars have conducted relevant studies. Some scholars have pointed out that energy consumption (Xia et al., 2019), economic growth (Chen et al., 2022), industrial knot adjustment (Shu and Xiong, 2019), and urbanization (Liu et al., 2021) are fundamental reasons for land use to influence carbon emission changes. Specifically, Cao and Yuan. (2019) agree that factors affecting land use-related carbon emissions are heterogeneous, with urbanization rate, and GDP per capita being the main influencing factors, while the proportion of land for construction, the proportion of secondary and tertiary industries and population size are secondary factors. Feng et al. (2022) and He and Zhang. (2022) find that changes in land use. Yang and Li (2022) suggested that carbon emissions continue to increase, but the growth rate decreased and has not yet reached its peak. Sun et al. (2020) found a significant effect of industrial land-intensive use on urban carbon efficiency, with significant positive effects of land-average labor, capital input, and science and education expenditure on carbon emission efficiency and adverse effects of land-average energy consumption.

In general, the existing literature sorting implies that land use has a greater influence on carbon emissions. However, scholars have only solely isolated the impact of land-intensive use on carbon emissions or carbon emission efficiency. Scholars have targeted their investigations at specific areas such as a city, a province and an urban agglomeration, and have not yielded uniform results either. Meanwhile, as the economy moves toward low-carbon transition, researches on land use are increasingly focused not only on the intensity, efficiency, and structure of land-intensive use on carbon emissions, but also the land-intensive use with coordinated and unified characteristics is getting increasingly attention among scholars. However, relevant researches still need to be further developed. In terms of the role path of land-intensive use on carbon emissions, among which industrial structure is the major attention of most scholars, but the depth and breadth of research are still lacking. Therefore, utilizing the panel data of 30 Chinese provinces over 2008-2020, this paper empirically analyzes the impact of land-intensive use on carbon emissions in China in terms of both carbon emissions and carbon emission efficiency using the entropy method to measure land intensive use. Besides, the role of industrial structure upgrading in influencing carbon emissions through land-intensive use is examined by using industrial structure rationalization and advancement as the mechanism variables.

TABLE 1 Carbon emission factors.

Fuel type	Default carbon content (kgc/GJ)	Default carbon oxidation rate	Average low level heat generation (KJ/kg, m^3)	Carbon emission factor (kgc/kg, m^3)
Coal	25.8	1	20908	0.53943
Coke	29.2	1	28435	0.8303
Crude oil	20	1	41816	0.83632
Gasoline	18.9	1	43070	0.81402
Kerosene	19.6	1	43070	0.84417
Diesel oil	20.2	1	42652	0.86157
Fuel oil	21.2	1	41816	0.88232
Natural gas	15.3	1	38931	0.59564

3 Methods, variables selection and data sources

3.1 Methods

To examine the effect of land-intensive use on carbon emission reduction, an econometric model was constructed and subjected to Hausman test and F-test in this paper. The test results support the two-way fixed-effect model considering year and individual factors. The baseline regression model is as follows.

$$CO_{it} = a + a_0 LIS_{it} + a_n Control_{it} + \mu_i + \nu_t + \varepsilon_{it} \quad (1)$$

where i and t each indicates time and area. CO is the carbon emission reduction indicator, including carbon emission (C) and carbon emission efficiency (CE). LIS_{it} is land intensive use level of each province. *Control* represents the control variables, including population (POP), environmental regulation (ER), foreign direct investment (FDI), urbanization ($URBAN$), green technology innovation (GTI). μ_i is the province fixed effect, ν_t is the year fixed effect, and ε_{it} is the random disturbance term. a is the proxy estimation coefficient.

3.2 Variables selection

3.2.1 Dependent variable

Carbon emissions (C). In the existing body of research, there is not a single, universal standard for determining how to measure carbon emissions. However, in general, carbon emissions mainly originate from the combustion of fossil energy, and thus the magnitude of carbon emissions can be estimated from the fossil energy consumed. This paper applies the epistatic method to measure carbon emissions. The specific carbon emissions are calculated by the formula:

$$C = k \cdot \sum_{h=1}^{n} E_h \cdot \delta_h \quad (2)$$

where C denotes CO_2. k ($k = 44/12$) is the CO_2 to carbon molecule weight ratio. E_h is the consumption of fossil fuel type h. δ_h is the emission factor of fossil fuel type h (see Table 1).

Carbon emission efficiency (CE). A formula for determining carbon emission efficiency is described below, which is dependent on the creation of a carbon emission indicator.

$$CE_{it} = \frac{GDP_{it}}{C_{it}} \quad (3)$$

where GDP is the gross domestic product.

3.2.2 Core explanatory variable

Land intensive utilization (LIS). Land intensive use refers not only to land use but also includes various other factors bearing on the ground. Land-intensive utilization is a comprehensive indicator of the coordinated utilization of land factors and other factors, mainly the relative production factors (Sun et al., 2020). Therefore, this paper measure land-intensive use and selects labor, energy, capital, science, and education as the index factors for evaluating land-intensive service. This paper measures land-intensive use of 30 provinces in China in four dimensions, including labor intensity, energy consumption intensity, capital expenditure intensity, and science and education investment intensity. This paper applies the entropy method to synthesize the four dimensions of land-intensive use level into a comprehensive indicator. Among them, labor intensity, capital expenditure intensity, and science and education investment intensity are positive indicators, and energy consumption intensity is negative (see Table 2).

3.2.3 Control variables

In order to reverse the endogeneity dilemma brought on by omitted variables, the following control variables, including total population (POP), environmental regulation (ER), foreign direct investment (FDI), urbanization level (URBAN), and green technology innovation (GTI), is introduced based on the literature of Ren et al. (2022), Jia et al. (2021), and Su et al.

TABLE 2 Comprehensive indicator system of land intensive use.

Variable	Measurement dimensions	Definitons	Sign
Land intensive use	Labor intensity (LB)	Ratio of number of employees to the area of urban construction land by province	+
	Energy emission intensity (EG)	Ratio of electricity consumption to urban construction land area by province	−
	Capital expenditure intensity (CI)	Ratio of fixed asset investment to urban construction land area by province	+
	Science and education investment intensity (SE)	The ratio of science and technology, education expenditure and urban construction land area in each province	+

TABLE 3 Variables definitions.

Var	Obs	Mean	Std	Min	Max
lnC	390	10.241	0.738	8.045	11.928
CE	390	0.661	0.460	0.139	3.256
LIS	390	0.362	0.148	0.057	0.782
lnPOP	390	8.195	0.744	6.317	9.443
lnER	390	2.633	1.037	−3.045	4.953
lnFDI	390	8.370	1.441	5.069	12.151
URBAN	390	0.570	0.131	0.291	0.896
GTI	390	7.045	1.530	2.485	10.732

(2021a) are constructed as follows. The year-end population of each province gauges the total population (POP). Environmental regulation (ER) is adopted to measure the amount of pollution control investment in each area. Foreign direct investment (FDI) is estimated with the amount of foreign investment in China and is treated at the current year's exchange rate of USD to RMB. At the close of the year, urbanization (URBAN) is represented by the urban population share. A higher level of urbanization means a higher level of industry, benefiting carbon emission reduction. As the quality of urbanization becomes better, a tipping point may appear in the impact on carbon emission reduction. Therefore, this paper introduces the quadratic term of urbanization level (URBAN2). The level of green technology innovation (GTI) may be gauged by looking at the number of patent applications submitted for green technology inventions as a percentage of total patent applications Zheng et al., 2(2022a).

3.3 Data

This paper selects panel data from 30 provincial-level administrative regions in China from 2008 to 2020 as the survey subjects. The data used are obtained from the China Economic Information Network, EPS database, WIND database, and the National Bureau of Statistics during the period under investigation. Meanwhile, to alleviate the problem of heteroskedasticity caused by the excessive volatility of the data, some variables are logarithmically treated in this paper. The variable's definitions are listed in Table 3.

TABLE 4 Baseline regression results.

Variables	(1)	(2)	(3)	(4)
	lnC	lnC	CE	CE
LIS	−0.204*	−0.361***	1.151***	0.844***
	(0.109)	(0.112)	(0.165)	(0.173)
lnPOP		0.720***		1.058***
		(0.173)		(0.268)
lnER		5.969		9.222
		(7.001)		(10.840)
lnFDI		0.010		−0.025**
		(0.007)		(0.010)
URBAN		1.368*		−0.868
		(0.766)		(1.186)
URBAN2		1.132		−1.826
		(0.770)		(1.192)
GTI		−0.0003		0.0007*
		(0.0002)		(0.0004)
Constant	10.00***	3.104**	0.179***	−7.312***
	(0.029)	(1.472)	(0.045)	(2.280)
Provine FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
N	390	390	390	390
Adj R^2	0.585	0.672	0.550	0.632

Note: Standard errors are reported in parentheses; ***, **, and * indicate significant at the 1%, 5%, and 10% levels, respectively. (Same below).

4 Analysis of empirical results

4.1 Analysis of baseline regression results

The estimated results of the impact of land-intensive use on carbon emissions are reported in Table 4. Columns (1) and (3) in Table 4 are the regression results without control variables; otherwise, they are those with the addition of

TABLE 5 Sub-dimensional regression results.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	lnC	lnC	lnC	lnC	CE	CE	CE	CE
lnLB	−0.043				0.060			
	(0.050)				(0.079)			
lnEG		0.378***				−0.370***		
		(0.043)				(0.073)		
lnCI			−.049*				0.168***	
			(0.029)				(0.045)	
SE				−0.220***				0.508***
				(0.081)				(0.127)
Control	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	390	390	390	390	390	390	390	390
Adj R^2	0.663	0.724	0.665	0.669	0.607	0.635	0.622	0.625

control variables. Columns (1) and (2) of Table 4 reveal that land-intensive use consistently and significantly reduces carbon emissions regardless of whether the control variables are added. Controlling for all variables, the coefficient of LIS is -0.361, implying that for every 0.1 unit increase in land-intensive use, carbon emissions will decrease by 3.61%. This indicates that the rise in the level of land-intensive services can save energy and contribute to carbon emission reduction. Columns (3) and (4) of Table 4 reveal that land-intensive use significantly improves carbon emission efficiency at the 1% level with a coefficient of 0.844 for LIS, i.e., for every 0.1 unit increase in the level of land-intensive use, carbon emission efficiency will increase by 0.0844 units. This indicates that growing land-intensive services can improve carbon emission efficiency by emitting fewer carbon emissions while obtaining certain economic benefits. Land-intensive use does not simply reduce carbon emissions but more significantly achieves this goal primarily by improving carbon emission efficiency. Developing a low-carbon economy through land intensification does not promote carbon emission reduction at the mere expense of economic growth but rather through improvements in land use efficiency. One potential explanation is that land-intensive use can optimize the allocation of technology, capital, energy, and other factors on the land (Sun et al., 2020), enabling enterprises to yield higher productivity and output with significantly lower energy and resource inputs. As a result, the production efficiency and capacity utilization of enterprises are subsequently boosted, thus making the carbon emission reduction sustainable (Wang et al., 2020).

4.2 Analysis of sub-dimensional regression results

The baseline regression results suggest that land-intensive use can contribute to drive carbon emission reduction. Which factors of labor intensity (LB), energy consumption intensity (EG), capital expenditure intensity (CI), and science and education investment intensity (SE) in drive this positive effect? Columns (1)-(4) and (5)-(8) of Table 5 reveal the impact of labor intensity, energy consumption intensity, capital expenditure intensity, and investment intensity in science and education on carbon emissions and carbon emission efficiency, respectively. Columns (1) and (5) of Table 5 reveal that the effects of land labor intensity on both carbon emissions and emission efficiency are insignificant. The higher the labor input intensity per unit of land, the higher the resulting economic output is generally (Ren et al., 2022). Therefore, it creates more possibilities for regions to boost emission reduction through new energy development and technological innovation, which improves the regional environment, facilitates urban carbon emission efficiency, and reduces carbon emissions (Hao et al., 2021).

However, such intensive use of land labor factors also implies that industrial activities are more active per unit of land, and more carbon emissions are generated by production and living. When the labor factor input reaches a certain level and adds additional information, the resulting economic return on investment will continue to decline, leading to lower carbon emission efficiency, inhibiting carbon emission reduction (Rehman et al., 2022). Therefore, the positive and negative effects of labor intensity increase of land on carbon emission and emission efficiency may cancel each other out and do not produce significant results.

Columns (2) and (6) from Table 5 reveal that the effect of land energy consumption intensity on carbon emissions is significantly positive and the impact on carbon emission efficiency is exceptionally negative. Higher land energy consumption intensity indicates that land use is more inclined to introduce high-energy-consuming enterprises, which are usually accompanied by high pollution and thus increase carbon emissions (Yin et al., 2022). The added value of high-energy-consuming enterprises is typically low. Due to the limitations of the regional economic development stage and factors existence such as excessive resource utilization caused by the traditional coal-based energy structure, the carbon emission scale expansion effect is greater than the economic efficiency enhancement effect, which is not conducive to improving carbon emission efficiency Zheng et al. (2022b). The intensive use of energy elements on land implies a lower intensity of land energy consumption, which can promote carbon emission reduction in terms of both carbon emissions and carbon emission efficiency.

Columns (3) and (7) in Table 5 reveal that capital expenditure land-intensive use can significantly reduce carbon emissions and substantially increase carbon efficiency, with a more substantial impact of capital-intensive land use on carbon efficiency. Increasing the intensity of capital investment per unit of land can strengthen the innovation effect of land spatial agglomeration and economies of scale. On the one hand, boosting capital investment intensity can attract more talent and provide infrastructure support for science and technology innovation (Ke et al., 2022). This not only forms a spatial agglomeration of mastery and innovation, promotes more advanced of low-carbon technologies, but also reduces carbon emissions of enterprises, makes less energy consumption per unit of economic output, and improves carbon emission efficiency (Wang et al., 2020). On the other hand, capital investment can also give solid financial support for the circular economy, promoting waste utilization, resource treatment, and recycling (Yang et al., 2022a). It reduces energy consumption while the economic output is further increased, and the carbon emission efficiency is more obviously improved (Kennedy, 2022). However, it should be noted that the increase in the intensity of land capital input per unit also leads to a rise in carbon emissions. Therefore, capital expenditure land-intensive use has a more substantial effect on improving carbon emission efficiency, while such effect is relatively weak.

Columns (4) and (8) of Table 5 reveal whether carbon emissions or carbon efficiency, science and education investment intensity can significantly affect it negatively and positively, respectively. Intensive investment in science and education factors generally cannot generate a significant increase in energy consumption (Keller et al., 2022). On the contrary, local governments can invest more science and technology (S&T) and education capital in the land to perfect the factors needed for S&T innovation and give enterprises human capital training and financial support for S&T (Lai et al., 2016). It helps enterprises to transform and upgrade to high value-added and low-pollution direction through technological innovation, thereby significantly reducing carbon emissions and improving carbon emission efficiency. As such, the promotion effect of land-intensive use on carbon emission reduction is mainly manifested in the intensive use of energy, capital, and science and education factors on the ground. In contrast, the intensive use of land labor does not significantly affect carbon emission reduction.

4.3 Analysis of robustness and endogeneity results

Considering that there may be a reverse causality between land-intensive use and carbon emission reduction, i.e., the higher the pressure of carbon emission, the more likely it is to force the improvement of land-intensive use in each area. For this reason, this paper uses the lagged period of the land-intensive use indicator as the instrumental variable (IV). The increase in land-intensive use will influence carbon emissions in the subsequent period. However, the carbon emission will not affect the land-intensive use level in the previous period. The first-stage regression results in column (1) of Table 6 implies that the land-intensive use level during the last period is significantly and positively correlated with the land-intensive use level in the current period because land-intensive use does not occur at once and has some inertia. Meanwhile, the Kleibergen-Paap RK F value is 395.745, significantly more significant than the critical value of 16.38, rejecting the weak instrumental variable hypothesis. The second stage regression are presented in columns (2) and (3) of Table 6, where the effects of land-intensive use on carbon emissions and carbon emission efficiency are significantly negative and significantly positive, respectively, in line with the baseline regression results above, demonstrating the robustness of the obtained results.

This paper also tries to conduct robustness tests. Firstly, the measurement method is replaced. This paper not only uses a fixed-effects model to examine the effect of land intensive use on carbon emissions but also opts for a random-effects model to test this (see columns (4) and (5) of Table 6). Second, possible omitted variables are controlled for. Local governments play a pivotal role in addressing the environmental problems caused by carbon emissions. And the behavior of local governments is mainly reflected through their interventions in the market. Local government expenditures are the financial basis for their intervention in the market to deal with carbon emissions. Therefore, this paper further controls for the local government intervention factor and uses local government fiscal expenditure to measure it (see columns (6) and (7) of

TABLE 6 Endogeneity and robustness test results.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	LIS	lnC	CE	lnC	CE	lnC	CE
L.LIS	0.717***						
	(0.036)						
LIS		−0.415***	0.999***	−0.466***	1.085***	−0.423***	0.771***
		(0.150)	(0.240)	(0.107)	(0.158)	(0.117)	(0.181)
lnGOV						0.153*	0.181
						(0.085)	(0.131)
Control	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	360	360	360	390	390	390	390
Adj R^2				0.708	0.642	0.674	0.633

Table 6). This paper finds that the sign and significance of core explanatory variables remain unaffected by significant changes, consistent with the baseline results.

4.4 Analysis of heterogeneity results

Due to economical and geographical factors, there may be differences in land-intensive use and carbon emission reduction between different regions (Su et al. (2021b); Yang et al., 2022b). On the one hand, whether land-intensive use can effectively promote carbon emission reduction is closely related to the level of local economic development. A higher level of economic growth means that a region has more capital, technology, and human resources, which can better meet the initial capital and technology investment required for land-intensive use. Based on this, this paper uses each province's per capita GDP indicator to strictly measure the regional economic development level. It constructs the interaction term *LIS*PERGDP* between land-intensive use and per capita GDP to examine the role of regional economic development level in land-intensive use to reduce carbon emissions.

On the other hand, this paper divides China into eastern and other regions according to their geographical locations. The eastern region has a more advantageous geographical location than other regions, with convenient transportation, more developed processing trade, and a higher overall economic development level, promoting the carbon emission reduction effect of land-intensive use (Wang et al., 2020). However, compared with other regions, the eastern region may have a more significant negative impact on local industrial development, especially energy-intensive processing trade, in the short term, which may affect its willingness to promote land-intensive use Zheng et al. (202a).This paper constructs dummy variables for land-intensive use concerning the eastern region and other regions to examine whether the carbon emission reduction promotion effect of land-intensive use is constrained by geographical location. Columns (1) and (2) of Table 7 reveal that the interaction term *LIS*lnPERGDP* has a significantly negative effect on carbon emissions but an incredibly positive effect on carbon emission efficiency. Economic development will not only consolidate the carbon emission reduction effect of land-intensive use but also enhance the carbon emission efficiency improvement effect of land-intensive use (Zhang and Wu, 2022). Compared with regions with lower economic development, regions with higher economic growth can provide more financial and technical support for further deepening land-intensive use, thus promoting carbon emission reduction more effectively.

TABLE 7 Influence mechanism results.

Variables	(3)	(1)	(2)
	RIS	AISN	AISQ
LIS	−0.526	2.808	1.582**
	(2.547)	(1.829)	(0.803)
Contol	Yes	Yes	Yes
Province FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
N	360	360	360

Columns (3) and (4) of Table 7 reveal that the interaction term *LIS*EAST* is insignificant for both carbon emissions and emission efficiency, indicating that geographical location insignificant moderating role in the process of promoting carbon emission reduction through land-intensive use. Compared with other regions, the eastern part can provide more substantial financial and technical support for land-intensive use by its relatively more developed economy, promoting carbon emission reduction.

However, there is a stronger incentive to maintain their processing trade development quickly. The willingness of local governments to promote intensive land use is relatively low, which makes their efforts to promote carbon emission through intensive land use not much different from those of other regions (Xia et al., 2019).

4.5 Analysis of influence mechanism results

The improvement of land intensive use is an important manifestation of optimizing the allocation of land resources, whose primary policy expectation is to regulate the industrial layout by regulating the ratio of land for secondary and tertiary industries in order to improve land factors allocation efficiency (Zhang and Wu, 2022). From the supply-side level, promoting intensive land use is a long-term national policy, and the enterprises that are compatible with it are bound to require being able to allocate the available resources reasonably for production and operation. This objectively promotes a low-carbon economy from the industrial structure toward the rationalization of energy usage and other resource allocation efficiency enhancement.

From the demand side, as local officials are prone to blindly pursue the increase of tertiary industry output value to obtain political achievements in order to obtain political promotion, they even support the development of high-cost and low value-added tertiary industries, making the industrial structure appear bubble. However, the objective requirement of promoting intensive land use restricts the entry of enterprises with low added value, serious pollution and backward development. At the same time, compared with the standardized and large-scale production of the secondary industry, the knowledge and technology-intensive tertiary industry tends to have higher added value and consume less energy, which is more in line with the need for land-intensive use. Therefore, the improvement of the level of intensive land use boost the quality of advanced industrial structure, which in turn promotes carbon emission reduction.

In order to test whether land intensive use can promote carbon emission reduction through industrial structure upgrading (i.e., industrial structure rationalization (AISN) and industrial structure advanced (AISQ)), this paper first constructs industrial structure rationalization and industrial structure advanced indicators. Among them, industrial structure rationalization reflects the level of industrial coordination and effective use of resources from the industrial aggregation dimension. In addition, the rationalization of industrial structure (RIS) is measured using the redefined inverse of the Theil index (Tian et al., 2021). The construction idea of Wang et al. (2022) is borrowed to calculate the quantity of industrial structure advanced (AISN) and the quality of industrial structure advanced (AISN). On this basis, this paper uses a two-stage least squares method to test the mechanism of industrial structure impact of land-intensive use for carbon emission reduction.

Columns (1) and (3) in Table 7 demonstrate the effects of land intensive use on AISN, the quantity of AISQ, respectively. Column (1) in Table 7 reveals that the effect of land-intensive use on AISN is insignificant, indicating that land-intensive use does not promote carbon emission reduction through the influence mechanism of AISN, which is different from the above analysis. This may be because although land-intensive use can promote AISN. However, local governments may set strong environmental protection thresholds to avoid high energy pollution enterprises in the process of promoting land-intensive use. In the short term this makes enterprises invest a lot of money in environmental protection, which leads to an uneven distribution of various factor resources and is not conducive to AISN (Zheng et al., 2022). As such, land intensive-use does inhibit carbon emission reduction through the channel of the AISN. As revealed by columns (2) and (3) in Table 7, land-intensive use promotes carbon emission reduction mainly through the quality of AISQ rather than the quantity of AISQ, which is consistent with our analysis. Land-intensive use is not just pursuing the bubbling of industrial structure, but lies in the development of tertiary industrial structure such as low-energy-intensive knowledge and technology, which promotes the quality of advanced industrial structure. This will not only promote the reduction of carbon emission reduction, but also enhance the efficiency of carbon emission by enabling regions to obtain higher economic returns with lower energy consumption.

5 Conclusions and policy recommendations

Against the increasingly severe global warming problem, curbing carbon emissions through rational land use has gradually emerged as a concern of existing research, while land-intensive use is the development direction of reasonable land use. For this purpose, this paper verifies the impact of land-intensive use on carbon emissions from the perspective of industrial structure upgrading by adopting the panel data set from 2008 to 2020. The research findings confirm that land-intensive use can reduce carbon emissions and increase carbon emission efficiency, which is mainly manifested in land energy factor, capital factor, science, and education factor intensive use. Compared with the regions with lower economic development levels, the carbon emission reduction effect of land-intensive use in the areas with higher economic development levels is more prominent. Finally, intensive land use promotes carbon emission reduction mainly through industrial structure advanced quality.

Combining empirical analysis and research findings, this paper puts forward policy recommendations from the following perspectives.

First, policymakers should vigorously promote the further deepening of land-intensive use in terms of intensifying energy, capital, and science and education on land. The central government should improve the original laws based on keeping abreast of the times, and pay attention to increasing exceptional financial support for the intensive development of energy, capital, science, and education elements on land. Guided by the central government, local governments should take advantage of local information to understand the existing situation of land-intensive use and formulate action plans to boost land-intensive use according to local conditions to inhibit carbon emissions.

Secondly, policymakers should consider the demands of economically backward regions when formulating laws and allocating special funds to drive land-intensive use. For example, while encouraging regions with higher economic development levels to deepen the intensive land use to boost carbon emission reduction, they are required to assist areas with lower growth levels in terms of capital, technology, and management, to help them to make some progress in land-intensive use.

Finally, policymakers should fully utilize o the quality of industrial structure advanced in the transmission of carbon emission reduction influence of land-intensive use. The deepening of land-intensive use leads to vertically upgrading land and industrial construction to achieve waste reduction. Meanwhile, focuing on enhancing the effect of land-intensive use in curbing carbon emissions through the channeling role of quality of the industrial structure advanced.

Although this paper explores the impact and role of land intensive use on carbon emission reduction based on industrial institutional upgrading, several limitations still exist. For example, future scholars can use big data technology to mine more micro data (at the prefecture and county levels) to quanlity the impact and mechanism of land intensive use on carbon emission reduction.

Data availability statement

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

Author contributions

HW conducted data collection and measurement, and wrote the text. MZ and DZ conceived of the research, made the structure, supervised this research work. YQ provided guidance on the methodology and an overall grasp of the logical structure of the text provided. SL and LY provided a great deal of assistance in data collection and organization, and in writing the text.

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Conflict of interest

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

Publisher's note

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