Pol. J. Environ. Stud. Vol. 34, No. 3 (2025), 2609-2626
DOI: *10.15244/pjoes/188228* ONLINE PUBLICATION DATE: 2024-09-16

Original Research

Evolutionary Game Analysis of the Government and Enterprises in the Low-Carbon Utilization of Urban Industrial Land: Evidence from China

Peichao Dai[1], Rongjia Zhang[2]*

[1]School of Public Administration, Nanjing University of Finance and Economics, Nanjing 210023, China
[2]Institute of Quantitative and Technological Economics, Chinese Academy of Social Sciences, Beijing 100732, China

Received: 1 February 2024
Accepted: 2 May 2024

Abstract

Achieving "carbon neutrality" through the reduction of carbon emissions from urban industrial land represents a significant endeavor. The government, which acts as the policy maker, and enterprises, which function as executors, are the principal stakeholders in low-carbon land utilization. Disparities between these entities may result in game-theoretic dynamics stemming from differences in resource allocation and objectives. Drawing from the empirical context of low-carbon industrial land utilization in China, this study examines the decision-making behaviors of bounded rational actors, formulates a payoff matrix for the government-enterprise game, and scrutinizes the strategic behaviors of both entities concerning low-carbon land utilization. The findings indicate that (1) while government subsidies incentivize enterprises to engage in low-carbon land use, these subsidies should be judiciously controlled; (2) the government can expedite enterprise low-carbon transformations by stipulating carbon emission reduction targets for industrial land and implementing rational penalty standards; (3) reduced production costs and appropriate government subsidies can bolster enterprises' inclination to adopt low-carbon development strategies; and (4) the facilitation of carbon derivative transactions and the provision of carbon finance can encourage enterprises to embrace low-carbon land use tactics. Additionally, the study offers policy recommendations for promoting low-carbon land utilization, including urban industrial land regulation, the adoption of low-carbon technologies, and the establishment of low-carbon industrial parks and carbon trading markets.

Keywords: Government-enterprise, evolutionary game, low carbon land use, urban industrial land

*e-mail: zhangrongjia@cass.org.cn
Tel.: +86-158-6211-4692

Introduction

A low-carbon economic development model is an inherent requirement of sustainable economic and social development and has gradually become an important symbol of high-quality development [1]. Although regional carbon governance entails positive externalities, the weakness of its incentive mechanisms tends to incline local governments toward relaxing environmental and carbon emission regulations in pursuit of economic growth. This tendency can exacerbate environmental pollution and carbon emissions [2]. Energy consumption and CO_2 emissions are considered primary drivers of the greenhouse effect [3]. China's economy has experienced decades of rapid development, which has laid a solid foundation for the improvement of people's living standards and the stability of the global industrial chain. However, with the rapid growth of China's economy, the drawbacks of high energy consumption and high emissions have gradually emerged [4]. In 2021, the added value of China's secondary industry accounted for 39.4% of the gross domestic product (GDP)[1], but energy consumption in the industrial sector accounted for approximately 65% of the total consumption of the country[2]. In particular, the heavy chemical industry is a key area of industrial energy consumption and greenhouse gas emissions. Six high energy-consuming industries, including steel, nonferrous metals, building materials, petrochemical, chemical, and electric power, account for approximately 71% of the carbon dioxide burned by industrial fossil energy[3]. Therefore, energy conservation and emission reduction in the industrial field are among the main areas for controlling carbon emissions and greenhouse gases.

Land use change is closely associated with carbon emissions [5], with the continuous expansion of urban industrial land notably emerging as a primary contributor to carbon dioxide emissions [6, 7]. In 2006, China surpassed the United States to become the largest carbon emitter in the world and is facing great pressure to reduce carbon emissions [8]. To control greenhouse gas emissions and alleviate the pressure of global warming, in line with the spirit of the Paris Agreement, China has proposed the "dual carbon" strategy, wherein it pledges to reach a carbon peak by 2030 and achieve carbon neutrality by 2060 [9]. As changes in land use structure affect human activities, especially economic activities, the optimization of the spatial layout of land use has become an important factor in carbon emission reduction [10]. From 2002 to 2020, the area of land utilized for construction sites in China increased by 96.57%[4]. To mitigate CO_2 emissions, the Chinese government has continuously implemented policies aimed at intensifying the utilization of industrial land [11]. Consequently, rational planning of the land use structure and enhancing the efficiency of industrial land utilization are considered pivotal strategies in the current phase to alleviate the pressure of carbon emissions [12, 13].

A modification in urban land usage patterns induces alterations in carbon emissions dynamics [14, 15]. In the relationship between different types of land use and carbon emissions, the expansion of industrial land has emerged as the primary driver of carbon emissions [16]. Despite the augmentation of the industrial land transfer scale that facilitates fixed asset investments and notably stimulates GDP growth, the rapid expansion of land supply diminishes urban spatial utilization efficiency [17-19] and consequently increases carbon emission intensity [20-22]. Industrial differences exist concerning the nexus between land utilization efficiency and carbon emission intensity [23], where industries characterized by low land utilization efficiency exhibit heightened carbon emission intensity [24]. To mitigate carbon emissions, several nations and regions have implemented diverse policies to regulate land utilization [25]. For instance, spatial optimization models have been established to forecast structural shifts in urban land usage under varying land utilization policies by constraining land usage types [26].

In the process of urban land use, due to the different interests and goals of the government and enterprises, the government follows strategies that are beneficial to itself in policy formulation and behavior selection. As the main body of market economic activity, enterprises aim to maximize their economic interests, but at the same time, their production methods and behaviors are affected by government policies. Although land transfer has brought financial benefits, the government still wants to optimize the supply and demand structure of the land market and adopt differentiated land prices and tax standards to guide the transfer of capital to low-carbon projects, thereby reducing carbon emissions. Therefore, guiding enterprises to gradually move toward low-carbon production is the government's preferred goal [27].

As an important way for the government to regulate and control the industrial structure, the policy trend of land affects the distribution of the land resources of enterprises. To meet the government's goal of low-carbon production, enterprises try to reduce carbon emissions by improving production efficiency. However, in this process, there is a game between the two. Therefore, this paper introduces game theory by establishing a game model between the government and enterprises and using the dynamic idea of evolutionary games to explore the relationship between the government and enterprises

[1] http://www.gov.cn/xinwen/2022-02/28/content_5676015.htm

[2] https://www.miit.gov.cn/gzcy/zbft/art/2022/art_e914dfd826ec46a89dd3b8194f735213.html

[3] https://www.miit.gov.cn/jgsj/jns/gzdt/art/2020/art_9a9a871faafc4c3c94fa273511ac10f5.html

[4] https://www.mohurd.gov.cn

in the low-carbon use of urban industrial land. This paper conducts in-depth research on the game model and analyzes the conditions and results to achieve game equilibrium. Studying the evolutionary game between governments and enterprises serves two main purposes. First, it reveals the influence of incentive and constraint mechanisms on the behavior of both parties, thereby offering insights and directions for the establishment of more effective policies and systems. Second, analyzing the strategic behaviors of governments and enterprises facilitates the identification of pathways and models for mutually beneficial cooperation, fostering synergistic development between governments and enterprises and advancing the practical implementation of low-carbon utilization transitions in urban industrial land.

Low-Carbon Utilization of Industrial Land in China

The Practice of Low-Carbon Utilization of Industrial Land in China

In 2011, pilot carbon emission trading was conducted in seven provinces and cities, including Beijing, Shanghai, Tianjin, Chongqing, Hubei, Guangdong and Shenzhen[5]. Fujian Province launched its carbon trading market in December 2016, becoming the eighth carbon trading pilot province in China. In July 2021, China's national carbon emission trading market was online for trading, and the local pilot carbon market was parallel to the national carbon market. In December 2020, the Ministry of Ecology and Environment of China issued the Measures for the Administration of Carbon Emission Trading (for Trial Implementation), which standardized national carbon emission trading and related activities, including carbon emissions quota allocation and payment, carbon emissions registration, trading, settlement, and greenhouse gas emissions reporting and verification. Units with annual greenhouse gas emissions that reached 26,000 tons of carbon dioxide equivalent are listed as key greenhouse gas emission units. By July 2022, 2,162 key emission enterprises in the power generation industry were included in the first performance cycle of China's carbon market, covering approximately 4.5 billion tons of carbon dioxide emissions annually and becoming the largest carbon market in the world (Appendix 1). The cumulative turnover of the carbon emission quota in the carbon market exceeded 190 million tons, and the cumulative turnover exceeded 8.5 billion Chinese yuan (CNY)[6].

In practice, low-carbon land utilization and low-carbon industrial land utilization both employ strategies such as adopting low-carbon technologies, optimizing land use structures, and enhancing resource utilization efficiency to achieve emission reduction goals. For example, for "low-carbon land use", to reduce carbon emissions and increase urban green coverage, a city implemented measures to construct vertical greening projects in its downtown area. These vertical greening buildings utilized techniques such as vertical planting, rainwater collection, and reuse to transform urban building surfaces into green vegetative coverings. This effectively mitigated the urban heat island effect, improved urban air quality, and concurrently reduced the city's carbon emissions. As an example of "low-carbon utilization of industrial land", a manufacturing enterprise implemented measures to reduce carbon emissions and enhance resource utilization efficiency by recycling industrial waste. Through process and technological improvements, the enterprise converted previously discarded production waste into reusable materials or energy sources. This action resulted in reduced carbon emissions during production processes and decreased consumption of natural resources to achieve low carbonization of industrial production processes.

Impact of Punishment on the Low-Carbon Utilization of Industrial Land

The low-carbon policies of the pilot provinces and cities show an obvious punitive nature. Punitive measures include fines, reducing carbon emission quotas, limiting subsidies, and a series of other policies. Taking Shanghai as an example, in addition to the punishment of key emission units for failing to fulfill their quota settlement obligations, the legal liability section of the Shanghai Pilot Measures for Carbon Emission Management stipulates punishment for failing to fulfill their reporting obligations, punishment for failing to accept verification as needed, the inclusion of credit information records, the disqualification of relevant support policies and other administrative measures, and covering the responsibilities of third-party verification institutions, the responsibilities of exchanges, and the administrative responsibilities of the staff of the development and reform departments and competent departments. According to the Measures for the Administration of Carbon Emission Trading (for Trial Implementation), the first performance cycle of the national carbon market was from January 1 to December 31, 2021. If it failed to perform the contract on time within this period, the local department of the ecological environment (at or above the level of the city divided into districts where its production and operation sites are located) ordered it to make corrections within a time limit and imposed a fine of not less than 20,000 CNY but not more than 30,000 CNY. If corrections failed within the time limit, the carbon emission quota for the next year was reduced by the competent provincial department of the ecological environment where the production and operation sites of key emission units are located. In other words, enterprises that "broke

5 https://www.ndrc.gov.cn

6 http://www.nea.gov.cn/2022-08/05/c_1310650391.htm

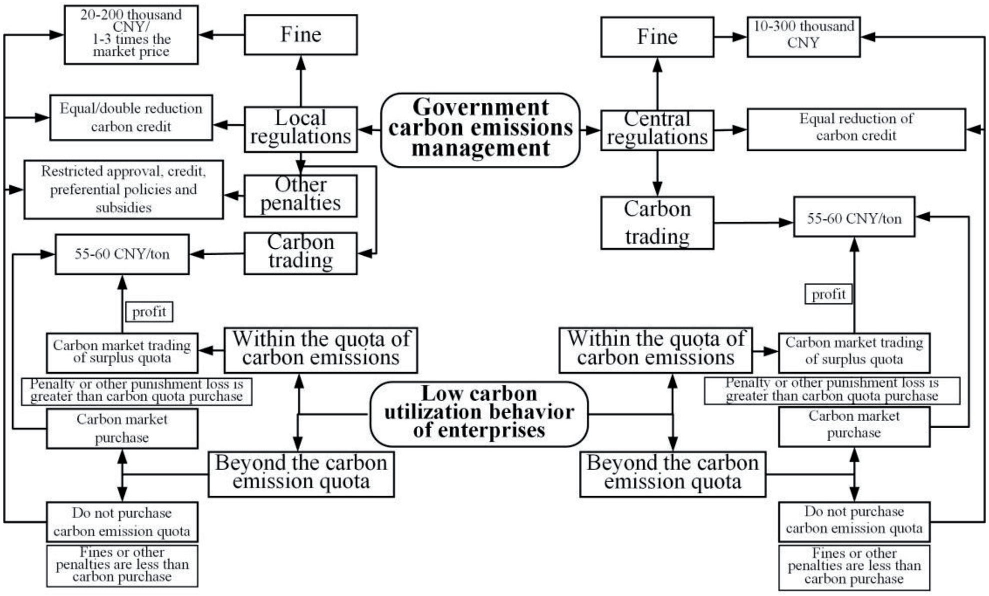

Fig. 1. The government-enterprise low-carbon utilization behavior process.

the contract" were not only required to rectify within a time limit but were also penalized (Fig. 1).

In the local carbon market, Shenzhen, Beijing, and Hubei all use multiple market prices of carbon quotas to impose fines, which increases the deterrent power of punishment. The carbon markets in Guangdong, Hubei, and Tianjin will be deducted at two times the quota next year. In addition, enterprises that fail to fulfill contracts are restricted by land transfer, government subsidies, and social credit. For example, in 2006, the Shandong Provincial Department of Land and Resources issued the Opinions on Further Strengthening Land Management, the land supply policy was tightened again, and high energy consumption and pollution projects no longer supplied land.

Although there are detailed penalties, some enterprises still choose not to perform. The low cost of fines is one of the reasons why some enterprises do not obey these rules. For some enterprises with a large carbon quota gap, the increased investment in transformation due to low carbon utilization together with the cost of carbon quota trading may far exceed a fine of 20,000 to 30,000 CNY, resulting in the phenomenon of fines instead of payments. However, the national carbon market is mandatory, and compliance is not an option for enterprises but rather a legal link that must be completed. To encourage enterprises to carry out low-carbon development, in March 2021, the Ministry of Ecology and Environment issued the Interim Regulations on the Administration of Carbon Emission Trading (Revised Draft) and solicited public opinion. It was proposed that if key emission units fail to pay off or to pay the carbon emissions quota in full, the local ecological environment administrative department should order them to make corrections and impose a fine of no less than 100,000 CNY but not more than 500,000 CNY. If no correction is made within the time limit, the provincial ecological environment department will reduce the part that is not fully paid by the same amount. This means that enterprises that fail to fulfill their contract will face higher violation costs.

In addition, the relatively low transaction price of China's carbon market indirectly led some enterprises to prefer to purchase quotas rather than carry out low-carbon transformation. In July 2022, the Chinese Emission Allowances (CEAs) price fluctuation range of China's carbon market remained between 55-60 CNY/ton (8.17-8.91 Dollars, 1 CNY≈0.14853 Dollars), while the average daily transaction price of the European Union (EU) carbon price in the same period was 80.56 EUR/ton, New Zealand fluctuated between 47-45 USD/ton, and South Korea's average carbon price was 13.48 USD/ton. The average price of the 31st auction of the carbon market in Quebec, California, in February 2022 was 30.52 USD/ton. The average auction price of the US carbon market in the second quarter of 2022 was 13.90 USD. The carbon trading prices in China and the major international carbon markets are quite different. Under the guidance of the goal of carbon neutrality, carbon market trading prices will increase with the participation of more industry enterprises, and the penalty cost of enterprises that do not follow low-carbon development will continue to increase (Appendix 2).

Impact of Carbon Finance on the Low-Carbon Use of Industrial Land

Carbon emissions trading provides carbon asset value, and the participation of market mechanisms provides carbon asset financial products with asset attributes. Industrial enterprises turn carbon resources into cash flows through the trading and investment of carbon emission rights and their derivatives.

This conversion promotes enterprises' low-carbon development, increases their profits through emissions reduction actions, and innovates the financial system. The first batch of enterprises included in carbon emission trading management are power, steel, cement, chemical industry, and other industries that took carbon emission rights as a tradable commodity and priced assets according to the supply and demand relationship of the carbon emissions market. The market-oriented pricing mechanism guides high energy-consuming industrial enterprises to examine the importance of carbon quotas and encourages enterprises to reduce emissions through technological innovation, transformation, and upgrading. At the same time, energy-consuming enterprises should comprehensively consider the purchase cost of carbon quotas when developing high-carbon projects. Through the carbon market trading system, enterprises are encouraged to save energy and reduce emissions, develop green industries with low energy consumption, and provide a basis for carbon neutralization.

The low-carbon development of industrial enterprises cannot be separated from financial support. The goal of carbon neutrality has given birth to "carbon finance", which develops "carbon" as an asset, plays the leveraging role of finance, and promotes the low carbon production of industrial enterprises. The State Environmental Protection Administration of China and the financial industry jointly launched a green financial system with green credit, green securities, green insurance, green funds, green trust, and green public-private partnerships (PPPs) as the main contents and provided financial products and services required for the low-carbon transformation of the industrial sector, such as transformation loans, transformation bonds, transformation funds, environment, social and governance (ESG) investment funds, climate funds, and climate bonds, to help enterprises save energy and reduce emissions through various financial products. It has also explored and innovated the establishment of carbon emission-related financial instruments, such as carbon futures, and carbon forward, which can not only increase market liquidity but also provide enterprises with hedging tools against carbon prices and climate change risks (Appendix 3). For listed companies to use mergers and acquisitions (M&As) to achieve the transformation of traditional industries and capacity transformation, priority should be given to the financing of emerging industries in the areas of low-carbon, environmental protection, green new energy in small and medium enterprise boards (SMEs) and the growth enterprise market (GEM). For enterprises that exceed the carbon emission quota in the region and do not actively purchase carbon emission quotas, the government should aim to make low-carbon transformations and eliminate underdeveloped production capacity. In addition, the impact of energy consumption and pollution on regional energy and industry should be analyzed against the existing risk points of overcapacity, and the credit risk management and control of industries with high energy consumption and high emissions should be strengthened.

Framework for Analyzing the Direct Influence of Governments and Enterprises on the Low-Carbon Utilization of Industrial Land

From the governmental perspective, there are three primary ways in which the government directly influences the low-carbon utilization of industrial land that has not yet been allocated. First, the government can establish low-carbon utilization standards by incorporating them into land allocation contracts, thereby mandating that enterprises adopt low-carbon measures during land utilization processes, such as the application of energy-saving and environmental protection technologies and the adoption of clean production processes. Second, the government can institute low-carbon land use quotas as one of the evaluation criteria for land allocation, providing preferential consideration or additional land incentives to projects that meet low-carbon requirements and thereby incentivizing enterprises to actively embrace low-carbon utilization practices. Third, the government can guide industrial restructuring through land allocation to prioritize projects aligned with low-carbon development objectives. For instance, allocating land for projects in new energy industries and environmental protection technologies fosters low-carbon industrial development.

For industrial land that has already been allocated, the government directly influences low-carbon land utilization through the following three mechanisms. First, it establishes incentive mechanisms whereby enterprises that comply with low-carbon utilization standards receive subsidies, encouraging the adoption of low-carbon practices. Simultaneously, enterprises that violate low-carbon requirements face penalties, while governmental supervision and management of land utilization practices are intensified. Second, the government supervises and regulates allocated industrial land more rigorously to ensure compliance with relevant low-carbon utilization standards and requirements. Strengthened oversight enables the timely identification and correction of noncompliant behavior, thereby prompting enterprises to adopt low-carbon measures. Third, the government provides technical support and training to enterprises with allocated industrial land, assisting them in understanding and mastering low-carbon technologies and methodologies. Through technical assistance and training initiatives, the government enhances enterprise capabilities in low-carbon practices, thereby promoting the transition toward low-carbon land utilization.

From the perspective of enterprises, there are several approaches to facilitating low-carbon land utilization. First, enterprises can engage in low-carbon utilization design by actively participating in the planning and design process of industrial land and proposing suggestions and requirements for low-carbon utilization.

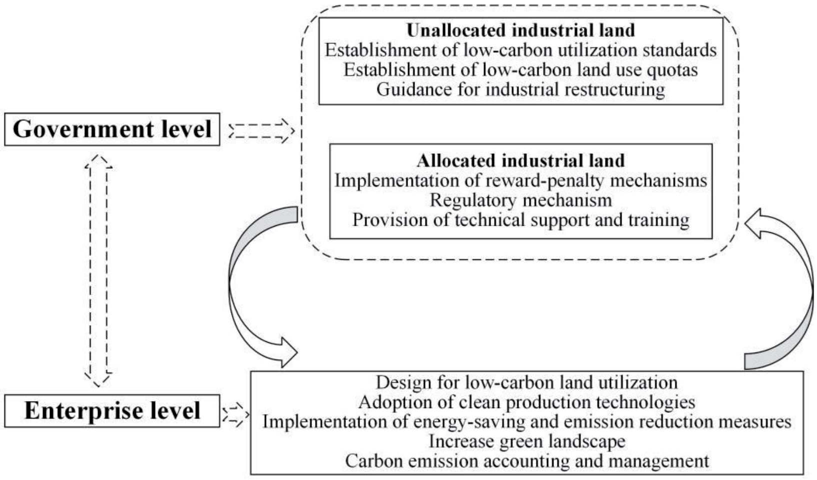

Fig. 2. Research framework on the direct impact of government and enterprise behaviors on low-carbon land utilization.

By incorporating low-carbon requirements into initial land utilization planning and design, enterprises can reduce future retrofitting and adjustment costs. Second, enterprises can opt for clean production technologies and equipment to minimize energy consumption and waste emissions during production processes. For instance, adopting efficient energy-saving equipment and promoting clean production processes can mitigate carbon emissions and environmental pollution. Third, enterprises can implement energy-saving and emission-reduction measures to simultaneously lower energy costs and carbon emissions. This may involve enhancing production processes, improving energy utilization efficiency, optimizing logistics and transportation, and reducing energy consumption and carbon emissions. Fourth, enterprises can enhance the carbon sequestration capacity of industrial land by introducing green landscapes. This may include planting green vegetation and constructing ecological wetlands within industrial land. Finally, enterprises can conduct carbon emission accounting and management, establish carbon emission monitoring systems, and devise emission reduction goals and plans. Through continuous monitoring and management of carbon emissions, enterprises can promptly identify issues and improve measures to achieve sustained reductions in carbon emissions. The research framework depicting the direct impact of government and enterprise behaviors on low-carbon land utilization is presented in Fig. 2.

Establishment of the Game Model

Basic Assumptions

This research classifies interest subjects in low-carbon land into two categories: local governments and enterprises. It is assumed that both parties have limited rationality when making decisions and that they consider the costs and benefits of the current behavior state and make their own behavior strategy choices according to the other party's behavior strategy.

For local governments, the degree of low-carbon land reflects performance, affects the competitiveness of the local economy in the regional development pattern, and is an assessment indicator of the superior government. The government usually has two strategies, namely, regulation and nonregulation. With regulation, the government invests a certain cost to regulate enterprises and provides different forms of subsidies to enterprises that implement low-carbon land use to reduce the economic pressure on enterprises and improve their enthusiasm for low-carbon use. For enterprises that are unwilling to implement low-carbon utilization, the government will also impose fines to promote low-carbon production. The second strategy is nonregulation; that is, the government does not take any measures to influence or interfere with the behavior of enterprises.

For enterprises, implementing low-carbon land use is an objective requirement for achieving sustainable development. On the one hand, sustainable economic development depends on the low-carbon production of enterprises, and the government regulates this at the policy level. On the other hand, the continuous adoption of low-carbon technologies can improve the competitiveness of enterprises and increase profits in the long run. Enterprises also have two strategies, namely, implementation and nonimplementation. First, industrial enterprises build green low-carbon parks or enter low-carbon industries supported by the government, adopt technological innovation to develop low-carbon products, and implement low-carbon production, for which the government may provide subsidies. The second strategy is to continue production with traditional high-consumption and high-pollution methods without implementing low-carbon production. However, this mode does not meet the requirements for low-carbon utilization of urban land and may be penalized by the government under government supervision.

Based on this realistic scenario, this paper focuses on local governments and enterprises. It is assumed that the two parties constitute a complete system of low-carbon evolution games, and their equilibrium and evolution processes depend on the game of participants' behavioral strategies. Evolutionary game theory based on the idea of biological evolution theory replaces mixed strategy in game theory with the percentage of individuals who choose different pure strategies in the population, which is helpful for analyzing decision-making behavior among limited rational subjects. This theory applies to research on the game behavior of both governments and enterprises in the process of low-carbon land use. Based on the above analysis, this paper proposes the following assumptions:

(1) Suppose that the local government needs to pay a certain institutional cost C_g when adopting the regulation strategy. The regulation methods are divided into subsidies and punishments. For enterprises that implement low-carbon production, the subsidies given by the government are recorded as S; for enterprises that do not implement low-carbon land use, the government imposes fines on them as P. Under the control of the government, if enterprises implement low-carbon production, they will achieve social benefits R_g.

(2) Assume that the cost of equipment and technology invested by enterprises when implementing low-carbon land use is C_f, the income obtained is recorded as R_f, and the subsidy obtained under government regulation is recorded as S. When the enterprise does not implement low-carbon land use, the cost of production is recorded as C_g', the income obtained is recorded as R_f', and the penalty is recorded as P under government regulation. Here, if the government regulates, it is assumed that whether the enterprise has implemented low-carbon land use will be determined.

Model Setting

As the main body for implementing low-carbon land use, the behavior of enterprises is closely related to the regulation and control policies of local governments, which is a dynamic adjustment process. Based on local governments and enterprises, this paper constructs a more detailed evolutionary game analysis model to provide a theoretical basis for subsequent policy optimization. According to the model assumptions, the payment matrix of the government and enterprises under different decision-making situations can be obtained. See Table 1 for details.

Model Analysis

Equilibrium Analysis of Local Government Decision-Making

Suppose that the probability of the government choosing the "regulation" strategy is $x(0\leq x\leq 1)$, and the probability of choosing the "nonregulation" strategy is $1–x$. The probability that the enterprise chooses "to implement low carbon land use" is $y(0\leq y\leq 1)$, and the probability that it chooses "not to implement low carbon land use" is $1–y$. From the game payment matrix, calculate the expected return of the government's choice of regulation strategy (U_1), the expected return of the choice of nonregulation strategy (U_2), and the average return of the government ($\bar{U}$), namely:

$$U_1 = P - C_g + (R_g - P - S)y$$

$$U_2 = 0$$

$$\bar{U} = xU_1 + (1-x)U_2 = [P - C_g + (R_g - P - S)y]x$$

The replication dynamic equation of the local government regulation strategy is as follows:

$$F(x) = dx/dt = x(U_1 - \bar{U}) = x(1-x)(U_1 - U_2)$$
$$= x(1-x)[(1-y)P + y(R_g - S) - C_g]$$

According to the stability principle of the replication dynamic equation, to achieve strategic stability, x must meet the following requirements: $F(x) = 0$, $F'(x)<0$.

If $y = \dfrac{P - C_g}{P - R_g + S}$, then $F(x) = 0$ is always true. Any value of x is a stable strategy. In addition, $x = 0$ and $x = 1$ are stable strategies.

Table 1. Payment matrix of the game between the government and the enterprise.

		Industrial enterprise	
		Implement low-carbon land use (L)	Do not implement low-carbon land use (UL)
Government	Regulate and control (R)	$U_{11} = R_g - C_g - S$ $V_{11} = R_f - C_f + S$	$U_{12} = P - C_g$ $V_{12} = R_f' - C_f' - P$
	Non regulation (UR)	$U_{21} = 0$ $V_{21} = R_f - C_f$	$U_{22} = 0$ $V_{22} = R_f' - C_f'$

At this point,
$F'(x)=(2x-1)[C_g-P+(P-R_g+S)y]$.

When $y>\dfrac{P-C_g}{P-R_g+S}$, $x = 0$ is in a stable state, that is, the local government chooses not to regulate the strategy; when $y<\dfrac{P-C_g}{P-R_g+S}$, $x = 1$ is in a stable state; that is, the local government regulates the strategy.

Equilibrium Analysis of Enterprise Decision-Making

In the same way, the expected income of the enterprise can be calculated when choosing the strategy of "implementing low carbon land use" (V_1), the expected income when choosing the strategy of "not implementing low carbon land use" (V_2), and the average income of the enterprise ($\bar{V}$), namely,

$$V_1=R_f-C_f+Sx$$

$$V_2=R_f{}'-C_f{}'-Px$$

$$\bar{V}=yV_1+(1-y)V_2=(R_f-C_f)y+(R_f{}'-C_f{}')(1-y)+(P+S)xy-Px$$

The replication dynamic equation of enterprise strategy is constructed as follows:

$$F(y)=dy/dt=y(V_1-\bar{V})=y(1-y)(V_1-V_2)=y(1-y)[(C_f-C_f{}')-(R_f-R_f{}')-(P+S)x]$$

According to the stability principle of the replication dynamic equation, to achieve strategic stability, y must meet the following requirements: $F(y) = 0$, $F'(y)<0$.

If $x=\dfrac{C_f-C_f{}'-R_f+R_f{}'}{P+S}$, then $F(y) = 0$ is always true. Any value of y is a stable strategy. In addition, $y = 0$ and $y = 1$ are stable strategies.

At this point,
$F'(y)=(2y-1)[(C_f-C_f{}')-(R_f-R_f{}')-(P+S)x]$

When $x<\dfrac{C_f-C_f{}'-R_f+R_f{}'}{P+S}$, $y = 0$ is stable, that is, the enterprise chooses not to implement a low-carbon production strategy, and when $x>\dfrac{C_f-C_f{}'-R_f+R_f{}'}{P+S}$, $y = 1$ is in a stable state, and enterprises choose to implement low-carbon production strategies.

Stability Analysis of the Equilibrium Point

To obtain the equilibrium solution of the game between the two sides, the dynamic simultaneous equation model is established:

$$\begin{cases}F(x)=dx/dt=x(1-x)[(1-y)P+y(R_g-S)-C_g]\\F(y)=dy/dt=y(1-y)[(C_f-C_f{}')-(R_f-R_f{}')-(P+S)x]\end{cases}$$

The equilibrium points of the system are (0,0), (0,1), (1,0, and (1,1). In addition, the following equation is established:

$$\begin{cases}(1-y)P+y(R_g-S)-C_g=0\\(C_f-C_f{}')-(R_f-R_f{}')-(P+S)x=0\end{cases}$$

$x=\dfrac{C_f-C_f{}'-R_f+R_f{}'}{P+S}$ and $y=\dfrac{P-C_g}{P-R_g+S}$ are also the balance points of the system. To facilitate the analysis of problems, we set $x_D=\dfrac{C_f-C_f{}'-R_f+R_f{}'}{P+S}$ and $y_D=\dfrac{P-C_g}{P-R_g+S}$.

According to the method proposed by Friedman, the Jacobian matrix of the system is constructed to judge the local stability of the equilibrium point of the evolutionary game. The Jacobian matrix of the evolutionary game can be obtained by computing the partial derivative of x and y with the above replication dynamic equation in turn:

$$J=\begin{bmatrix}\dfrac{d\dot{x}}{dx} & \dfrac{d\dot{x}}{dy}\\ \dfrac{d\dot{y}}{dx} & \dfrac{d\dot{y}}{dy}\end{bmatrix}$$

Among them,

$$\begin{cases}\dfrac{d\dot{x}}{dx}=(2x-1)[C_g-P+(P-R_g+S)y]\\ \dfrac{d\dot{x}}{dy}=x(x-1)(P+S-R_g)\\ \dfrac{d\dot{y}}{dx}=y(y-1)(-P-S)\\ \dfrac{d\dot{y}}{dy}=(2y-1)[(C_f-C_f{}')-(R_f-R_f{}')-(P+S)x]\end{cases}$$

Table 2. Jacobian determinant analysis of the system.

Local equilibrium point	$\det J$	tr$J$
(0,0)	$(P-C_g)[-(C_f-C_f{}')+(R_f-R_f{}')]$	$-(C_f-C_f{}')+(R_f-R_f{}')+(P-C_g)$
(0,1)	$(C_g-R_g+S)[-(C_f-C_f{}')+(R_f-R_f{}')]$	$(C_f-C_f{}')-(R_f-R_f{}')+(R_g-S-C_g)$
(1,0)	$(C_g-P)[-(C_f-C_f{}')+(R_f-R_f{}')+P+S]$	$-(C_f-C_f{}')+(R_f-R_f{}')+)(C_g+S$
(1,1)	$(R_g-S-C_g)[-(C_f-C_f{}')+(R_f-R_f{}')+P+S]$	$(C_f-C_f{}')-(R_f-R_f{}')+)(C_g-R_g-P$
(x_D, y_D)	$(P-C_g)(C_g-R_g+S)[-(C_f-C_f{}')+(R_f-R_f{}')$ $+P+S][(C_f-C_f{}')-(R_f-R_f{}')]$ $/[(P+S)(P-R_g+S)]$	0

If the trace condition of the Jacobian matrix is satisfied (the sum of the elements on the diagonal of the Jacobian matrix is less than 0) and the Jacobian determinant condition is satisfied (the determinant is greater than 0), they are recorded as tr$J$ and det$J$, respectively. The equilibrium point of the copied dynamic equation is the local stability point, which is the stability strategy of the evolutionary game. As shown in Table 2, tr$J$<0 is not satisfied at the local equilibrium point (x_D, y_D), so the equilibrium point (x_D, y_D) is not an evolutionary stability point. Therefore, only the asymptotic stability of the remaining four equilibrium points in the table is considered.

When $P<C_g$ and $C_f - C'_f > R_f - R'_f$ is satisfied, the cost of government regulation is greater than the income from fines, and the increased cost of enterprises implementing low-carbon land use is also greater than the income difference. At this time, the government is not willing to regulate, and enterprises are not willing to implement low-carbon land use. Then, the evolution strategy of the government and enterprises is (0,0), namely, "no regulation and control, no implementation of low carbon land use".

When $R_g<S + C_g$ and $C_f - C'_f < R_f - R'_f$, the social benefits obtained by government regulation are less than the sum of government regulation costs and subsidies paid by the government, but the increased benefits from enterprises' implementation of low-carbon land use are greater than their increased costs. Therefore, the government's willingness to regulate is not high, but enterprises are more willing to implement low-carbon use because they can obtain greater benefits through the low-carbon use of land. At this point, the evolution strategy of the government and enterprises is (0,1) to "implement low-carbon land use without regulation and control".

When $P>C_g$ and $C_f - C'_f > R_f - R'_f$, the fines collected by the government when implementing the regulation can cover its regulatory costs. For enterprises, under the government's regulation strategy, the costs of not implementing low-carbon land use include production costs and fines paid. The government can subsidize the implementation of low-carbon land use, but in this case, the extra costs paid by enterprises when implementing low-carbon land use are still greater than their income difference. Therefore, the government is more willing to implement regulation, but enterprises are unwilling to implement low-carbon utilization. At this point, the evolutionary strategy of the government and enterprises is (1,0), namely, to "regulate and control without implementing low-carbon land use".

When $R_g>S + C_g$ and $C_f - C'_f < R_f - R'_f + S$, the social benefits obtained by the government when implementing regulation and control are greater than the costs and subsidies paid, and the income difference obtained by enterprises when implementing low-carbon land use is also greater than the costs paid. Therefore, the government is willing to implement regulations, and enterprises are willing to use low-carbon land. Then, the evolution strategy of the government and enterprises is (1,1), that is, "regulate and implement low-carbon land use".

It can be seen from the above conclusions that appropriate adjustment of government regulation policies can enable enterprises to implement low-carbon land use with a greater probability and maintain this strategy in an evolutionary and stable state. The government's subsidy policy for enterprises can reduce the cost of developing low-carbon technologies and implementing low-carbon utilization, improve the probability of low-carbon land use, and encourage enterprises to actively carry out reform. Similarly, punishing enterprises that do not implement low-carbon land use will force enterprises to transform. Therefore, the government's introduction of a standardized and reasonable subsidy and punishment mechanism can encourage enterprises to carry out low-carbon transformation, improve the benefits of enterprises' low-carbon land use, and thus promote green low-carbon development.

Numerical Simulation Analysis

To verify the evolutionary game model and its analysis results constructed in this research and to further analyze the impact of government regulation policies and the cost-benefit changes of low-carbon technologies on the implementation of low-carbon land use strategies by enterprises, MATLAB is used to simulate and analyze the relevant behaviors of the government and enterprises. The key to establishing the simulation model is to describe the internal regular pattern of changes to a certain extent. The parameter setting is mainly based on the change law of various relevant factors and their sensitivity to the strategies of both sides of the evolutionary game, which does not represent the payment or income of both sides of the game in the real land low-carbon system, without losing generality. This study assumes that all exogenous variables are positive. Based on these assumptions, this research sets the parameter value as $C_g = 1$, $R_g = 2$, $C_f' = 1$, $R_f' = 1$ and the initial value is $(x, y) = (0.5, 0.5)$.

Impact of Government Subsidies on System Evolution

Under the condition that the government's fines and the costs and benefits of low-carbon land use implemented by enterprises remain unchanged, suppose $P = 1$, $C_f = 2$, $R_f = 3$, and we analyze the impact of changes in government subsidies on system evolution. Taking S as 0.2, 0.5, and 2, the impact of these variables on the government's regulation strategy is shown in Fig. 3, and the impact of these variables on the enterprise's low-carbon land use strategy is shown in Fig. 4. With the increase in subsidy expenditure within a certain range, although the government will eventually choose to implement the "regulation" strategy, its evolution speed will decrease; when the government needs to receive more subsidies, the government will not implement the "regulation" strategy. However, for enterprises, the more government subsidies there are, the faster they choose to implement low-carbon land use strategies. On the one hand, increasing government subsidies can stimulate enterprises to implement low-carbon land use efficiently; on the other hand, they can compensate for the capital consumption of enterprises in low-carbon technological innovation and encourage enterprises to use low-carbon land more quickly. However, over a long enough period, the government's subsidies will not affect the convergence effect of enterprises. Enterprises will eventually choose to implement low-carbon production technologies because the benefits after low-carbon production are greater, but excessive subsidies will affect the government's willingness to regulate. Therefore, although government subsidies encourage enterprises to implement low-carbon land use, the subsidy strategy should be controlled within a reasonable range.

Impact of Government Fines on System Evolution

Assuming that the cost and benefit of government subsidies and enterprises' implementation of low-carbon land use remain unchanged and that $S = 0$, $C_f = 2$, $R_f = 3$, the impact of changes in the intensity of government fines P on system evolution is analyzed. The P values are set to 0.2, 0.8, and 2, and their impacts on the government's regulation strategy are shown in Fig. 5. The impact of these factors on enterprises' low-carbon land-use strategies is shown in Fig. 6. With the increase in fines, the government's rate of change to the "regulation" strategy is faster. Similarly, for enterprises, the government forces them to implement low-carbon transformation by imposing fines. The more fines there are, the faster enterprises will implement low-carbon land-use strategies. Of course, in a sufficiently long

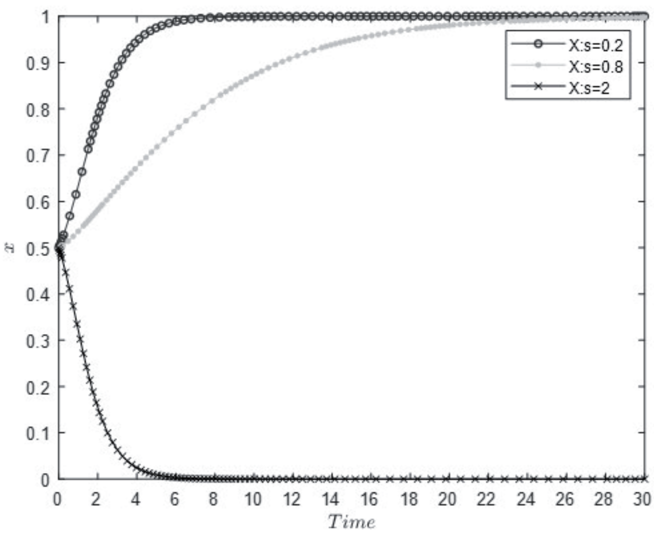

Fig. 3. Impact of government subsidies on government strategies.

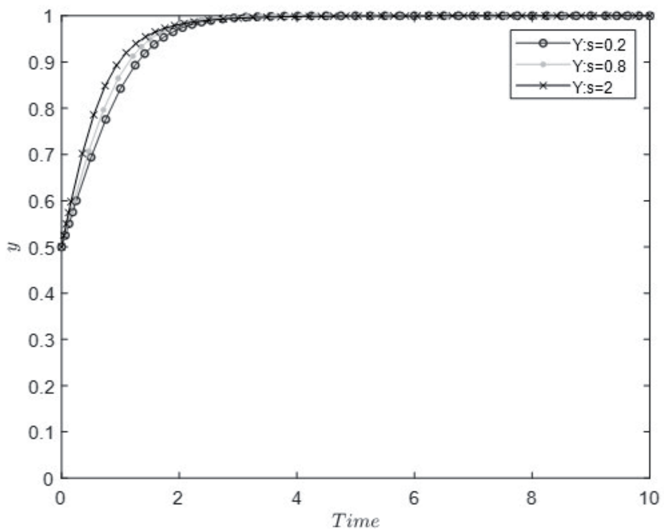

Fig. 4. Impact of government subsidies on enterprise strategies.

time, fines will stop affecting the convergence results of the government and enterprises. The government will eventually choose to implement the "regulation" strategy because it can offset part of the government's regulation costs. Enterprises will eventually choose to implement low-carbon land use, and the benefits will be greater after low-carbon land use. Therefore, the government can set reasonable fines according to the low-carbon target to improve the low-carbon transformation speed of enterprises.

Impact of the Low-Carbon Transformation Cost of Enterprises on System Evolution

Under the condition of keeping government subsidies, fines, and benefits of low-carbon land use implemented by enterprises unchanged, suppose $S = 1$, $P = 1$, $R_f = 3$. We analyze the impact of changes in the cost C_f of low-carbon land use implemented by enterprises on system evolution. Taking C_f as 1.2, 2, and 10, respectively (it is assumed that the cost of implementing low-carbon land use by enterprises must be greater than that of not implementing low-carbon land use by enterprises), its impact on the enterprise's low-carbon land use strategy is shown in Fig. 7. For enterprises, if the cost of implementing low-carbon land use is only slightly greater than the cost of not implementing low-carbon land use, enterprises will evolve to implement low-carbon land use strategies, but with increasing cost, the rate of change will continue to decrease. When the cost of implementing low-carbon land use is very high, enterprises will choose not to implement low-carbon land use because the benefits cannot cover the costs. Therefore, enterprises can reduce costs through cooperation and economies of scale, and the government should provide subsidies to make up part of the investment of enterprises to improve their willingness to use low-carbon land.

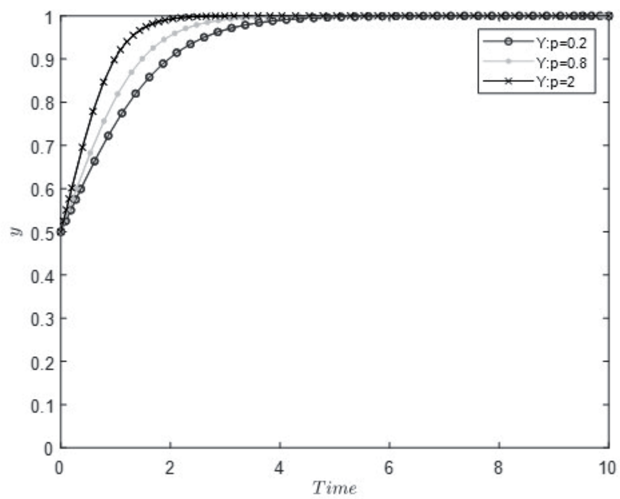

Fig. 5. Impact of government fines on government strategies.

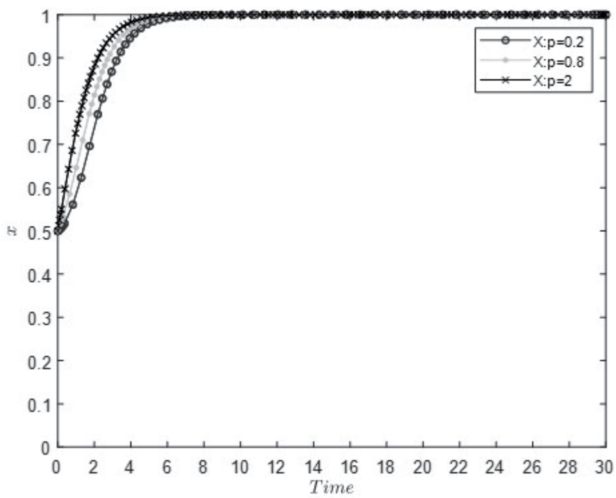

Fig. 6. Impact of government fines on enterprise strategies.

Impact of the Low-Carbon Transformation Benefits of Enterprises on System Evolution

Under the condition that government subsidies, fines, and the cost of low-carbon land use implemented by enterprises remain unchanged, assume $S = 1$, $P = 1$, $C_f = 2$. We analyze the impact of changes in the cost R_f of low-carbon land use on system evolution. We set R_f to 0.2, 3, and 10, and their impact on enterprises' implementation of the low-carbon land use strategy is shown in Fig. 8. For enterprises, if the benefits of implementing low-carbon land use are less than those of not implementing low-carbon land use, they will evolve to the strategy of not implementing low-carbon land use, whereas if the benefits of implementing low-carbon land use are greater than those of not implementing low-carbon land use, the enterprise will evolve to the strategy of implementing low-carbon land use, and its evolution speed will accelerate with increasing benefits. Therefore, the publicity of carbon derivatives should be increased and the efficiency and coverage of carbon trading should be improved to improve corporate income and promote low-carbon land use.

Conclusion and Policy Recommendations

Conclusions and Limitations

The stakeholders involved in low-carbon land use mainly include local governments and enterprises. Enterprises are the main actors in the low-carbon utilization of urban industrial land, and their low-carbon transformation or willingness to use low-carbon technologies influences the effectiveness of low-carbon utilization. The local government establishes low-carbon policies for urban industrial land and intervenes in low-carbon use. In the game with enterprises, information and institutional advantages influence the effect of low-carbon land use. To maximize the benefits of low-carbon

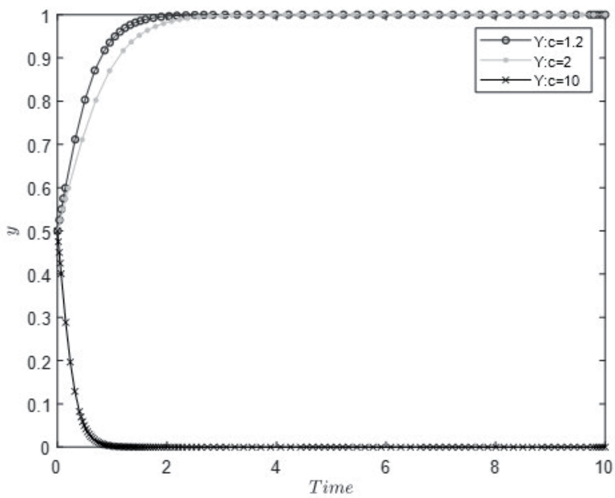

Fig. 7. Impact of low carbon transformation costs on enterprise strategy.

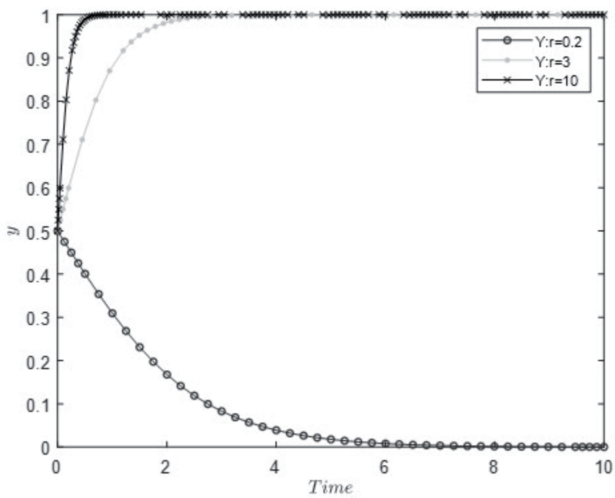

Fig. 8. Impact of low-carbon transformation benefits on enterprise strategy.

utilization of urban industrial land, we need to rely on a combination of regulation and incentives.

According to the analysis of the evolutionary game model and system dynamics simulation results, the following conclusions can be drawn: (1) the government's low-carbon policy will affect the low-carbon use of urban industrial land; (2) government subsidies will encourage enterprises to implement low-carbon land use, but the subsidy proportion should be reasonable and controllable; and (3) when the benefits of implementing low-carbon land use are greater than those of not implementing low-carbon land use, the strategy of low-carbon land use will be more attractive, whereas when the benefits of implementing low-carbon land use are less than those of not implementing low-carbon land use, low-carbon land use policy cannot play a positive role. Therefore, this paper explored the low-carbon utilization path of urban industrial land to realize the green development of urban industry and promote the virtuous circle of urban industrial ecosystems.

In many cases, the goals of local governments and enterprises may align, particularly in promoting economic growth and development. However, it is crucial to recognize that the objectives of the central government, which often include broader national economic and environmental considerations, may not always align perfectly with those of local governments and enterprises. For example, while local governments and enterprises may prioritize short-term economic gains, the central government may emphasize long-term sustainability and environmental protection. However, when facing low-carbon land utilization by enterprises, both central and local governments share common goals in terms of setting and implementing regulatory standards. While there may be differences between the short-term and long-term economic development goals of the central and local governments, it is challenging to distinguish between parameters attributed to the central and local governments due to data limitations. Therefore, this study categorizes both the central and local governments as a single entity termed "government."

Policy Recommendations

This study aims to improve the regulation system for urban industrial land use. Urban industrial land is the spatial carrier of industrial development. Therefore, it is important to optimize the industrial structure, achieve low-carbon land use, and promote industrial green upgrading by relying on land control approval and other ways to regulate industrial land. The government should use economic means of regulation, such as adopting policies that entail fines and subsidies, to subsidize enterprises that develop and use low-carbon land to reduce production costs. For industrial projects with a low level of repeated construction, high energy consumption, and high carbon emissions, the scale of land use will be restricted. For example, the government needs to formulate policies to limit carbon emissions, increase penalties for enterprises that do not use land with low carbon emissions and exceed carbon emissions, and adopt administrative means to regulate carbon emissions. In areas where industrial land is scarce or ecologically sensitive, the land supply should be concentrated in high-tech-intensive industries. Following the development idea of a low-carbon economy, carbon emission standards should be formulated according to industrial categories, carbon emission reduction targets should be compared, and industrial land access, construction, and carbon emission standards should be set.

Transforming high-carbon industries to low-carbon industries and developing clean energy are fundamental ways to reduce the carbon emissions of industrial land. The low carbonization of industrial land is a new type of utilization mode that combines "low energy consumption, low pollution, and low emissions". This not only has advantages for the realization of carbon emissions reduction goals but is also conducive to industrial upgrading and sustainable economic development. Governments should support green industry project land use and establish a full life cycle management model for industrial land. Enterprises should transform and upgrade their existing technology and establish a low-carbon technology support system to reduce costs, increase profits, and achieve sustainable development. Enterprises should also correctly address the low-carbon transformation, actively respond to the national low-carbon development strategy, strive for government incentive policy support, and avoid punitive measures. In the short term, enterprises need to increase investment and reduce economic benefits to implement low-carbon land use, but in the long run, low-carbon land use can reduce energy consumption and increase economic, social, and ecological benefits.

To improve the carbon trading market, the enthusiasm of industrial enterprises for energy conservation and emission reduction and the further reduction of emissions under the quota set by the government must be mobilized. Excess carbon emission quotas can be transferred to other high-emission enterprises, forming a carbon emission reduction fund pool. However, enterprises with excessive carbon emissions can only obtain quotas through the carbon emission trading market. When the purchase cost is higher than their own emission reduction cost, a cost-driven mechanism will be formed to promote their own energy conservation and consumption reduction, thus producing a positive low-carbon development effect.

Acknowledgments

This research was supported by the Jiangsu Provincial Social Science Application Research Elite Project (24SYC-020); General Project of Philosophy and Social Science Research in Colleges and Universities in Jiangsu Province (2023SJYB0265); Nanjing Social Science Foundation (23ZN02); Special funding of Nanjing Soft Science Research Program (202303014); Jiangsu Provincial Committee Agriculture Office and Provincial Department of Agriculture and Rural Affairs Rural Revitalization Soft Science Project (23ASS050); and CASS Laboratory for Economic Big Data and Policy Evaluation (2024SYZH004). Simultaneously, the authors would like to express their gratitude to undergraduate students Qisihan Chen, Bingxuan Zhu, Huihan Lin, Jiahao Wang, and Yuchen Xiao for their assistance in data collection and processing for this paper. The authors are also grateful for the comments from the associate editor and the reviewers.

Conflict of Interest

The authors declare no conflicts of interest.

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Appendix 1. Inclusion criteria for carbon markets in China in 2021.

	Region	Inclusion criteria	Number of enterprises	Industries
1	Beijing	5,000 tons and above	886	Power production industry, cement manufacturing industry, petrochemical industry, thermal power production and supply industry, service industry, and road transport industry
2	Tianjin	20,000 tons and above	160	15 industries including electric power, steel, and chemical industry
3	Shanghai	20,000 tons and above	323	27 industries including power, steel, chemical, aviation, etc.
4	Guangdong (except Shenzhen)	20,000 tons and above	178	Cement, steel, petrochemical, paper, and other industries
5	Shenzhen	3,000 tons and above	750	Computer, communication and electronic equipment manufacturing, and other industries
6	Hubei	26,000 tons and above	396	Steel, cement, chemical, and other industries
7	Sichuan	26,000 tons and above	51	Thermal power generation and cogeneration plants
8	Chongqing	20,000 tons and above	152	Cement, steel, petrochemical, and other industries
9	Fujian	26,000 tons and above	40	Power, steel, chemical, petrochemical, nonferrous metals, civil aviation, building materials, paper making, ceramics, and nine other industries
10	Hunan	26,000 tons and above	33	Power, chemical, and other industries
11	Inner Mongolia	26,000 tons and above	172	Power, medicine, energy, chemical industry, etc.
12	Shandong	26,000 tons and above	327	Power, petrochemical, chemical, building materials, steel, paper making, nonferrous metals and other industries
13	Jiangsu	13,000 tons and above	500	Petrochemical, chemical, building materials, steel, nonferrous metals, paper making, power, and other industries
14	Jiangxi	26,000 tons and above	43	Electric power, medicine, chemical, and other industries
15	Henan	26,000 tons and above	118	Electric power, chemical industry, etc.

Appendix 2. Penalties for exceeding the carbon emission quota and failing to perform as needed.

Region	Date	Enterprise	Content	Penalty amount (10,000 CNY)
Beijing	2014.07	Baisheng Commercial Development Co., Ltd	Carbon emissions exceed the quota by more than 500 tons	13.75
	2014.07	Beijing CBRE Property Management Service Co., Ltd	Exceeding the quota by tens of thousands of tons	275
	2014.07	Microsoft (China) Co., Ltd	More than 400 tons of carbon emissions exceeded the quota	11
Jiangsu	2022.03	Changzhou Guangyuan Thermal Power Co., Ltd	Failure to pay carbon emission quota in full and on time	2
	2022.03	Zhangjiagang Junma Polyester Products Co., Ltd	Failure to pay carbon emission quota in full and on time	2
Guangdong	2015.05	Shenzhen Container Co., Ltd	Excess carbon emission quota of 4,928 tons	63.36
Inner Mongolia	2022.04	Dongfang Hope Baotou Rare Earth Aluminum Co., Ltd	The uncompleted contract amount is 2,459,675 tons	3
	2022.09	Manzhouli Lianzhong Thermal Power Co., Ltd	Failure to pay carbon emission quota in full and on time	2.5
	2022.07	Beikong Urban Services (Ewenki Autonomous Banner) Co., Ltd	Case of violation of carbon emission trading management system	3
	2022.03	Hulun Buir North Pharmaceutical Co., Ltd	Failure to pay carbon emission quota in full and on time	2
	2022.07	Inner Mongolia Baiyecheng Alcohol Manufacturing Co., Ltd	Failure to pay carbon emission quota in full and on time	2
	2022.05	Olunchun Autonomous Banner Lintai Property Service Co., Ltd	Failure to pay carbon emission quota in full and on time	1.1
	2022.03	Chifeng Pharmaceutical Co., Ltd	Failure to pay carbon emission quota in full and on time	3
Ningixa	2022.04	Six enterprises including Ningxia Baofeng Energy Group Co., Ltd., Ningxia Risheng Hi tech Industry Co., Ltd., and Ningxia Keomei Bioengineering Co., Ltd	Failure to pay carbon emission quota in full and on time	16.8
Heilongjiang	2022.01	A thermal power plant in Yichun City	The carbon emission quota was exceeded by 53,625 tons, and the carbon emission quota was not paid in full	2
Shanghai	2020.02	Shanghai Shidongkou No.1 Power Plant of Huaneng International Power Co., Ltd	False greenhouse gas report	1.88
Zhejiang	2021.12	Xinchang County Thermal Power Group Co., Ltd	Incomplete carbon quota settlement	2
Henan	2022.05	A thermal power enterprise in Wuzhi County, Jiaozuo	Failure to pay carbon emission quota in full and on time	2
Jilin	2022.06	A development limited company	Failure to pay carbon emission quota on time	2
Sichuan	2022.01	Sichuan Jiuda Salt Manufacturing Co., Ltd., Zigong, Sichuan	Failure to pay carbon emission quota on time	2.6
	2022.01	Qingshen Huali Taji Thermal Power Co., Ltd	Failure to pay carbon emission quota on time	2
Guangxi	2021.06	Guangxi Yongkai Bridge Paper Co., Ltd	Failure to pay carbon emission quota on time	2.1251
	2022.05	Guangxi Fangchenggang Hongyuan Pulp and Paper Co., Ltd	Failure to pay carbon emission quota on time	2.1563

Note: Punishment standard and basis
Beijing: The Decision of Beijing on Carrying out the Pilot Work of Carbon Emission Trading on the premise of strictly controlling the total amount of carbon emissions states that "the carbon emissions beyond the scope of the quota permission shall be punished at three to five times the average market price."
Guangdong: The Interim Measures of Shenzhen Municipality on the Administration of Carbon Emission Trading "impose a fine of three times the average market price of the carbon emission quota that has not been paid."

Appendix 2. Continued.

Shanghai: The Tentative Measures of Shanghai for the Management of Carbon Emissions state that a fine of more than 10,000 CNY but less than 30,000 CNY should be imposed for false reporting, concealment, or refusal to perform reporting obligations.
The Jiangsu, Inner Mongolia, Ningxia, Heilongjiang, Zhejiang, Henan, and Jilin Measures for the Administration of Carbon Emission Trading (for Trial Implementation) state that "if the carbon emission quota is not paid in full and on time, a fine of not less than 20,000 CNY but not more than 30,000 CNY will be imposed".

Appendix 3. Carbon finance-related policies and practice cases.

Region	Date	Financial institutions	Enterprise	Financial support	Collateral
Beijing	2021.09	Beijing Green Exchange, Bank of Beijing	Beijing Shengtong Printing Co., Ltd	Loan of 10 million CNY	Carbon emission right
Tianjin	2021.08	Industrial and Commercial Bank of China Tianjin Branch	Dagu Chemical Co., Ltd	Loan of 10 million CNY	400,000 tons of transferable carbon quota
Shanghai	2021.08	BNP Paribas, Societe Generale, Credit Agricole Orientale, Banque Nationale Francaise	Total Vision Energy Services (Shanghai) Co., Ltd	510 million green loans	——
	2021.08	Agricultural bank	A chemical company in Shanghai	Loan 5 million	Carbon emission right
	2022.05	Shanghai Branch of CPIC Property&Casualty Insurance Co., Ltd., Shanghai Ring Exchange, Bank of China Shanghai Branch	Shanghai Huafeng Superfiber Materials Co., Ltd	"Carbon quota+pledge+insurance"	Carbon emission right
Jiangsu	2021.08	Taixing Rural Commercial Bank	Taixing Xinpu Chemical Co., Ltd	Loan 5 million	110,000 tons carbon emission quota
Zhejiang	2021.08	Industrial and Commercial Bank of China Rui'an Sub-branch	Zhejiang Huafeng New Materials Co., Ltd	Loan 5 million	160,000 tons of carbon emission quota
Chongqing	2017.04	Chongqing Branch of Industrial Bank	Chongqing Minfeng Chemical Co., Ltd	Loan 50 million	Carbon quota pledge financing
Shandong	2021.08	Yishui Rural Commercial Bank	Shandong Fiberglass Group Co., Ltd	Loan 20 million	More than 700,000 tons of carbon emission quota
	2022.04	Shandong Guoxin	Shangao Huaneng Group	200 million CNY trust limit	Revenue right of 6 million tons of carbon emissions
	2022.08	Weifang Bank	Anqiu Thermal Power Co., Ltd	Loan 2 million	Carbon emission right
Hubei	2014.09	Industrial Bank	Hubei Yihua Group	Loan 40 million	4 million tons of carbon emission quota
Guizhou	2021.08	Minsheng Bank	Guizhou Jinyuan Qianxi Power Plant of State Power Investment Corporation	Loan 28 million	Carbon emission right
Jiangxi	2021.08	China Construction Bank Jiangxi Branch	Shenhua Guohua Jiujiang Power Generation Co., Ltd	Loan 100 million	3,418,900 tons of carbon emission right
	2021.08	Jiujiang Bank	Ganzhou Huajin Paper Co., Ltd	Bank acceptance bill 5 million	Carbon emission right quota as pledge guarantee
Gansu	2021.08	China Everbright Bank Lanzhou Branch	Jiugang Hongsheng Electric Heating Co., Ltd	Loan 40 million	1.87 million tons of carbon emission quota
Heilongjiang	2022.10	Harbin Bank	A thermal power plant in Jixi	Loan 10.5 million	Carbon emission rights to be purchased by enterprises in the future