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How to Construct a Carbon Asset Management System for Chinese Power Enterprises: A Survey-Based Approach

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Abstract: The greenhouse effect of atmospheric pollution is globally concerning. China is transitioning to market-driven emission reduction from policy-driven efforts. In 2021, key power industry emitters were included in the national carbon trading market. However, many companies lack willingness and understanding of carbon assets, hindering progress. Research on power companies in Beijing, a political and carbon market pilot region, is valuable. This study obtained data on the participation of Beijing's power generation companies in the carbon market and the construction of their carbon management systems during the first compliance period through the distribution of surveys. The findings revealed that the implementation and preparation of carbon inventory, Chinese Certified Emission Reduction (CCER) development, the allocation of carbon management personnel, and training are key factors influencing the actual effectiveness of carbon management within companies. Based on the survey results and the impact pathways, this study outlines the preparatory work, system content, and construction steps for power companies to build a carbon management system. It summarizes five key areas of work for power companies in managing carbon assets: carbon inventory, carbon management personnel and mechanisms, carbon trading, carbon emission reduction, and carbon finance. This provides guidance to help power companies fulfill their obligations smoothly, add value to their carbon assets, and achieve low-carbon development goals. Additionally, it offers a reference for other industry enterprises that are about to enter carbon trading.

Keywords: carbon assets management system; carbon trading; power enterprises; questionnaire survey method

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1. Introduction

With the rapid development of the economy and society, environmental protection has become a new theme of the times. In the grand global blueprint for carbon reduction, China is contributing its own experience and thinking. In order to move more efficiently towards achieving carbon neutrality, China has shifted from policy-driven emission reduction to market-driven emission reduction in recent years, taking steps to establish a national carbon market and improve carbon trading mechanisms. China successfully established carbon emission trading pilots in seven provinces and cities in 2011 and completed the overall design of the carbon emission trading system in 2017 [1]. In recent years, the carbon trading market in China has been rapidly expanding. In 2020, the "Administrative Measures for Carbon Emission Trading (Trial)" and supporting quota allocation plans and lists of key emitters were released, which came into effect on 1 February 2021, which marked the official launch of the first compliance period of the national carbon market in early 2021 [2]. Carbon assets, as carbon emission rights, carbon emission reductions, and other derivatives that can affect an organization's greenhouse gas emissions under mandatory or voluntary carbon emission trading mechanisms, need to be of concern to the first batch of power companies included in the national carbon market. Power companies urgently need to establish a sound carbon asset management system to achieve carbon asset appreciation

on the basis of smooth compliance. However, due to limited experience in carbon trading, most power generation companies are still in the exploratory stage, and their management systems are not yet mature or even fully formed.

Scholars at home and abroad have conducted research on carbon asset management from several main aspects:

1.1. Carbon Assets

As early as the late 20th century, some scholars had organized and summarized the quota carbon emission rights that restrict carbon dioxide emissions and considered this right as an evolving form of asset. Subsequently, Marland et al. [3] first explained the definition of carbon assets, considering carbon assets as a result of the allocation of carbon emission rights due to environmental capacity constraints, rather than simply as a tradable asset. The value of carbon assets can only be realized in carbon emission trading. However, as scholars from various countries further studied sustainable development, the definition of carbon assets continued to expand. Chevallier [4] pointed out that carbon assets include the surplus carbon dioxide owned by enterprises and their derivative financial products, not limited to the carbon emission rights allocated by the system. In later studies, scholars attempted to define carbon assets in broad and narrow terms [5], classifying them according to different purposes as obligatory, transactional, or of investment expenditure in nature [6]. Recently, domestic scholars have begun to attribute financial commodity attributes to carbon assets [7].

1.2. Carbon Asset Management Systems and Achieving Effective Carbon Emission Reduction

Under the carbon trading system, effective emission reduction is an inevitable choice for the healthy and sustainable development of power companies. In the long term, the carbon emission trading market can significantly improve emission reduction by promoting green technological innovation [8]. However, for companies that cannot achieve effective emission reduction in the short term, when the cost of purchasing quotas exceeds the income from power generation, these companies are likely to choose to abandon or sell part of their power generation rights [9].

Under the carbon market mechanism, in order to achieve long-term development, power companies must engage in effective emission reduction and carbon management. Regarding emission reduction, Xinkuo Xu et al. [10] found that distributed photovoltaic power generation has advantages in energy conservation and emission reduction, but its economic value is not yet clear and is greatly influenced by carbon prices. Liu Y et al. [11] found that the boundary of the survival environment for key emitting enterprises is mainly defined by technological improvements in carbon emission utilization. Under the carbon trading mechanism, key emitting enterprises have to improve their technology to achieve emission reduction, and traditional thermal power plants may be forced to transition to new energy sources.

An increasing number of scholars believe that in order to achieve effective emission reduction, power companies need to establish a carbon asset management system suitable for themselves and put it into operation as soon as possible. Burritt et al. [12] called for the establishment of a carbon emissions management accounting framework to help companies strengthen carbon management and achieve emission reduction in their research as early as 2011. Subsequently, Caiping Zhang et al. [13] attempted to construct carbon asset management indicators through the study of a company's carbon management practices, demonstrating the positive role of carbon asset management in emission reduction. Shen Y et al. [14] studied 1780 companies and found that carbon management practices such as emission reduction targets are positively correlated with equity market value. Tuesta, YN et al. [15] believed that changes in emissions have positive and significant effects on all financial performance indicators of companies. The above studies all confirm that companies using environmental management systems have indeed reduced their negative impact on the environment to some extent [16] and have brought positive effects on company value and performance.

1.3. Discussion on the Current Situation and the Content of a Carbon Asset Management System

Despite facing increasing pressure for carbon emission reduction, key emitting enterprises in China are not proactive in carbon asset management and the construction of the carbon market. They do not give enough importance to the construction of the carbon asset management system conceptually, resulting in low efficiency in emission control [17]. Yang Guangjun et al. [18] found, through an analysis of the current status of carbon emissions in typical power generation enterprises, that due to weak profit expectations brought about by carbon trading, lack of professional personnel, and relatively insufficient understanding of relevant policies and technical methods, most power generation enterprises have an observing attitude towards the carbon market. Li Yunsong et al. [19] analyzed the main problems of domestic enterprise carbon management, including the imperfect carbon asset management system, the imbalance between the cost and benefits of emission reduction, and the uneven development.

In the discussion of carbon management content and methods, existing research mainly focuses on carbon information acquisition and disclosure, management personnel, carbon trading management, potential carbon emission reduction measures, and carbon risk management.

In the terms of carbon inventory and information disclosure, Hrasky [20] stated that the disclosure rate of carbon footprints is increasing, but most companies only disclose carbon footprints to meet government requirements; Liu Z et al. [21] opined that the overall quality of carbon information disclosure in Chinese-listed power companies is low, indicating weak capabilities in representing corporate carbon management behaviors. Chen Na [22] attempted to construct a management system based on the carbon lifecycle, including carbon asset planning and accounting management, carbon asset operation and risk control management, carbon asset information disclosure management, and carbon asset operation performance management. The application of this system in case study enterprises validated its feasibility and necessity, confirming the importance of carbon asset inventory planning.

Regarding carbon management personnel and mechanisms, Jiang Y et al. [23] stated that the low-carbon awareness of management has a significant positive impact on corporate carbon management and low-carbon development; Hu Xiaoyu et al. [24] proposed the establishment of a subsidiary or department for carbon asset management in large power generation groups, involving professional talents in carbon trading and green energy trading, and developing voluntary emission reduction projects.

With respect to the carbon trading market and strategies, Song, HY et al. [25] proposed that China's carbon market is facing coordination issues with the electricity market, and there are linkages between carbon prices and electricity prices. Wang Peng [26] proposed a coupled trading model for wind power generation companies participating in the electricity spot market, considering uncertainty. The analysis found that through multiple rounds of bidding, wind power generation companies can obtain the optimal market strategy in the medium to long term. Additionally, risk preference trading optimization models can quantify potential losses caused by wind uncertainty, aiding in risk control in the spot market for wind power generation companies.

Carbon emission reduction and carbon finance: Scholars generally agree that power companies need to achieve long-term healthy development through emission reduction. However, research on the carbon finance investment market in China is still in its early stages. Tao Chunhua [27] used event analysis to examine the Chinese capital market's reaction to companies' registration of CDM emission reduction projects under the United Nations. They found that the impact of project registration in high-carbon-emitting industries on stocks is more significant than in other industries, due to many imperfect policies and systems in carbon asset strategic planning and information disclosure; further development is urgently needed. Yu Chenxin [28] used the data of a wind power plant to calculate and analyze the trading strategies of the wind–hydrogen–fire multi-energy coupling system in the existing model in different markets and the corresponding power

generation and emission reduction; it was concluded that carbon emissions can be reduced indirectly by increasing the financial benefits, which fully affirms the positive effect of the financial market on emission reduction.

Existing research mainly uses methods such as policy document analysis, market effects, and corporate performance data to provide suggestions related to carbon information disclosure, carbon trading management, carbon asset management, personnel allocation, and carbon emission reduction. Many studies also analyze the potential risks in carbon markets. In the past year, some research has begun to explore the field of carbon finance markets. However, scholars have not yet reached a consensus on the definition of carbon assets, which is still evolving with ongoing research. Additionally, the field of carbon asset management has not formed a mature professional theory. Most existing research is based on the initial formation of carbon asset systems in enterprises, analyzing the necessity of constructing carbon asset management systems, the impact of carbon management on enterprise value and performance, and how to enhance management professionalism while reducing costs. There is a lack of a complete review of the steps for constructing carbon asset management systems and an investigation into the specific problems that enterprises face in building such systems. This paper, based on a large number of emission control policies and corporate management literature, has developed a guidance plan for power companies to construct a carbon management system, summarizing the system into five main tasks based on the business' nature. In order to understand the current management status of enterprises and the factors influencing management effectiveness, this paper collected data on the current carbon management status of 150 power companies in Beijing. The data was processed and analyzed using descriptive statistics, correlation analyses, and the establishment of a multiple regression model. Based on the analysis results and the impact path, exploratory development suggestions were proposed from both the enterprise and government levels.

2. Background Description

China is expected to achieve carbon peaking around 2030, complete comprehensive emission reduction and transformation of the primary industry by 2045, and reach carbon neutrality around 2060. In recent years, China has successively issued multiple emission control policies and trading methods, which can be roughly divided into three categories: command-based, market-based, and voluntary environmental regulations. For example, the Carbon Emissions Trading Management Measures (Trial) policy, issued in 2020, significantly promotes the innovation and efficiency of emission reduction for enterprises [29].

With the power industry being included in the carbon trading market, major power companies are facing carbon scrutiny, and the importance attached to carbon business is increasing. Most energy state-owned enterprises and central enterprises have established professional carbon asset management companies. The five major power generation groups, including the China Datang Corporation, China Huaneng Group, China Huadian Corporation, State Energy Investment Group, and State Power Investment Corporation, have all established their own carbon asset management companies and actively constructed management platform procedures to serve their own carbon asset management. However, few other power companies have established subsidiaries or dedicated departments to manage carbon assets. Their experience and capabilities in carbon emission management need to be improved [30].

The current carbon asset management in the power industry mainly faces the following three problems [31]:

(1) Data Aspect

There is a lack of inventory capability for carbon emission data, and the foundation is very weak. In 2019, among the 3939 listed companies in the Chinese A-share market, more than 70% of the companies did not disclose relevant environmental information reports. According to the 2020 Carbon Disclosure Project (CDP) China Supply Chain Report, 60% of suppliers provide direct operational carbon emission data, but only 9%

disclose carbon emission data verified by third-party independent verification. Not only is the disclosure quantity small and the credibility low, but there are also problems with the small verification scope and short time series.

(2) Technical Aspect

The cost of emission reduction technology is high, and the supporting system is incomplete, especially for renewable energy such as wind power and photovoltaics. Although the technology itself has entered a mature stage, the industrial application still faces issues such as long-distance transmission, energy storage, and power grid system mechanisms. These problems have led to most companies lacking the motivation to prioritize high-cost emission reduction schemes, with only a few companies focusing on low-carbon technology research and development.

(3) Trading and Financial Aspect

The carbon market is dominated by a single entity, and its activity is weak. Emission control enterprises have not yet established a complete carbon asset management system, and trading is mainly for compliance purposes as a large-scale demand has not developed. The financial attributes of carbon assets have not been fully realized.

Currently, the quality of basic carbon emission data in Chinese power companies needs to be improved, the alignment of carbon reduction paths with the company's own development situation is not high, and the coordination of management across different departments of the company needs to be strengthened. Therefore, there is an urgent need to establish a scientific and systematic carbon emission management method.

3. Investigation into the Construction of Carbon Asset Management Systems in Some Power Generation Enterprises in Beijing

3.1. The Basis for the Questionnaire Design

(1) The Process of Power Generation Enterprises Participating in Carbon Trading:

At the beginning of the compliance period, the provincial ecological and environmental authorities allocate quotas to key emitting units based on the actual output and the quota calculation formula that was verified without error in the previous year, as well as the carbon emission baseline within the administrative region [32]. During the compliance period, key emitting units and entities and individuals complying with national trading rules act as trading entities, with carbon emission quotas as the trading products (additional types possible). Trading entities conduct transactions through the national carbon emission rights trading system, using agreement transfer, one-way bidding, or other compliant methods. Key emitting units settle quotas at the beginning of each year as required and report and undergo the verification of greenhouse gas emissions in the previous compliance period, in a continuous cyclical process. The process of enterprise participation in the carbon trading process is illustrated in the following figure (Figure 1).

(2) Carbon Asset Management System for Power Enterprises:

In recent years, the newly developed concept of carbon performance measurement has been considered to evaluate the effectiveness of enterprise carbon asset management [33]. Carbon assets refer to carbon emission rights, carbon emission reductions, and other derivatives that directly or indirectly affect an organization's greenhouse gas emissions under mandatory or voluntary carbon emission trading mechanisms. By analyzing the carbon trading mechanisms, participating entities, and processes, the current enterprise carbon management research aims to achieve compliance and value enhancement through participation in trading and adherence to the principle of sustainable, low-carbon development; the preparation work, system content, and construction steps for power enterprises to establish a carbon management system are outlined. The management of carbon assets for power enterprises is summarized into five categories: carbon inventory, carbon management personnel and mechanisms, carbon trading, carbon emission reduction, and carbon finance (Figure 2).

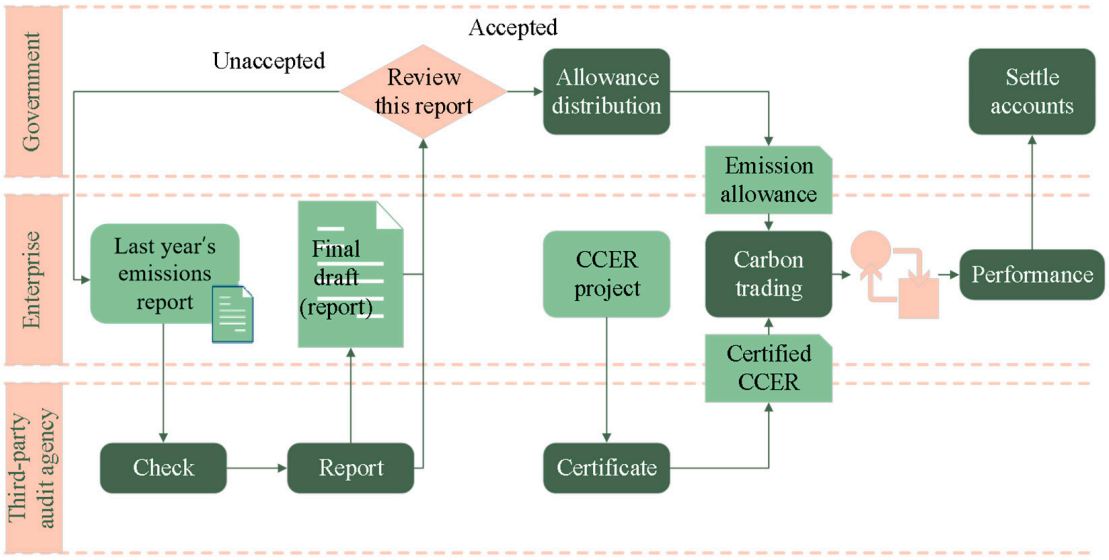


Figure 1. Flowchart of power generation enterprises participating in carbon trading.

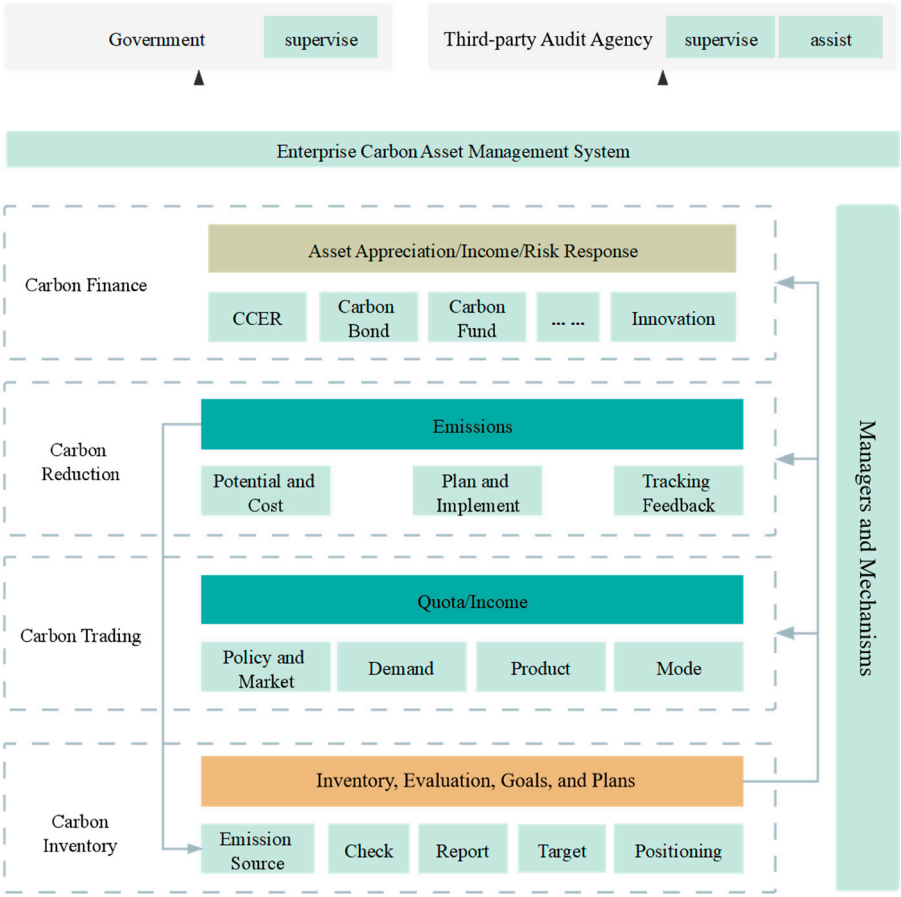


Figure 2. Structure of carbon asset management for power generation enterprises.

3.2. Questionnaire and Research Design

Based on the trading mechanism, processes, and involved entities, and considering the characteristics and framework of the carbon asset management system for power generation enterprises, the questionnaire in this study follows the principle of moving from easy to difficult in its design, aiming to obtain information from the survey subjects in five aspects: basic information about the enterprises, attitudes and goals, systems and

management systems, operational processes, and outcomes. The questionnaire consists of a total of 28 test questions (see Appendix A). The samples in this study are derived from a research project titled "Construction status, completeness, and existing issues of the carbon asset management system for power generation enterprises in Beijing", conducted by the author in collaboration with Suzhou Zhongyan Network Technology Co., Ltd. (https://www.wenjuan.com/about/, accessed on 28 July 2024). The questionnaires were distributed to senior management personnel in active service at power generation enterprises in Beijing. After receiving the questionnaire data, Suzhou Zhongyan Network Technology Co., Ltd. determined the validity of the questionnaires based on the registrational information of the respondents' companies and their registration information on carbon trading websites. The data were processed and analyzed using SPSS Statistics 26, GraphPad Prism Version 9.4.1 and Excel software Version 2021, according to the different requirements for data analyses.

3.3. Descriptive Statistical Analysis of Sample

A total of 150 surveys were distributed to senior management personnel of power generation enterprises in Beijing by Suzhou Zhongyan Network Technology Co., Ltd. in order to obtain representative enterprise data. The surveys were distributed in accordance with the registered information of the respondents' companies and the registration information on the carbon trading website by the cooperating research company to determine the validity of the questionnaires and to eliminate duplicate questionnaires that were filled out by the same company. A total of 150 valid questionnaires were collected. The structure of the survey sample is shown in Table 1.

Table 1. Sample structure of the questionnaire survey.

	Option	Frequency	Percentage	Average Value	Standard Deviation
Whether it is a key emission unit	Yes	79	53%	1.47	0.50
	No	71	47%		
Number of official employees	Under 50	44	29%	2.61	1.40
	50–100	33	22%		
	101–150	32	21%		
	151–200	20	13%		
	More than 200	21	14%		
The main way of generating electricity (up to two)	Thermal power generation	63	42%	0.42	0.50
	Hydroelectric power generation	53	35%	0.35	0.48
	Wind power generation	54	36%	0.36	0.48
	Photovoltaic power generation	25	17%	0.17	0.37
	Biological power generation	18	12%	0.12	0.33
	Geothermal power generation	8	5%	0.05	0.23
	Tidal power	4	3%	0.03	0.16
	Other green electricity	23	15%	0.15	0.36
Comprehensive average energy consumption range in the past three years (ton of standard coal/year)	<5000	65	43%	1.68	0.67
	5000–10,000	68	45%		
	≥10,000	17	11%		
Carbon emission status	Almost achieved carbon neutrality within the company.	6	4%	4.16	1.18
	Already peaked, but not yet achieved carbon neutrality within the company, and continuing to reduce emissions.	13	9%		
	Not yet peaked, and is expected to peak by 2025.	19	13%		
	Not yet peaked, and is expected to peak by 2030.	25	17%		
	Not yet peaked, uncertain about the time to reach carbon peak.	87	58%		
Whether participated in carbon emission rights trading (2021)	Yes	74	49%	1.51	0.50
	No	76	51%		
Total		150	100%	—	—

3.4. The Analysis Results of Goal, Attitude, Management Status, and Effect

(1) Analysis of Enterprises' Attitudes Toward the Carbon Market

According to the survey results (as presented in Figure 3), the proportional ratio of surveyed individuals who believe that the dual-carbon targets put pressure on enterprises and those who believe it is beneficial to enterprises is close to 1:1. Key emission units are more inclined to believe that the dual-carbon targets put pressure on enterprises than non-key emission units. Among all surveyed individuals who believe that the dual-carbon targets put pressure on enterprises, 93% consider "facing increasingly stringent emission reduction policies" as one of the reasons; the reason "increased power generation costs, decreased profit expectations" accounts for 56%. It is preliminarily speculated that carbon inspection, trading, and other work have increased the management costs of enterprises; at the same time, the higher cost of thermal power generation in the power generation industry is putting pressure on it. Among the surveyed enterprises that believe the dual-carbon targets are beneficial to enterprises, 60% believe that "market competitiveness has increased, and profit expectations have risen", and most of them are non-key emission units; 60% believe that "emission reduction work has received strong policy support". It is speculated that non-key emission units are subject to relatively loose emission control policies, resulting in less cost increase compared to key emission units and relatively increased market competitiveness. At the same time, the government's support for power generation enterprises has also been recognized by the enterprises.

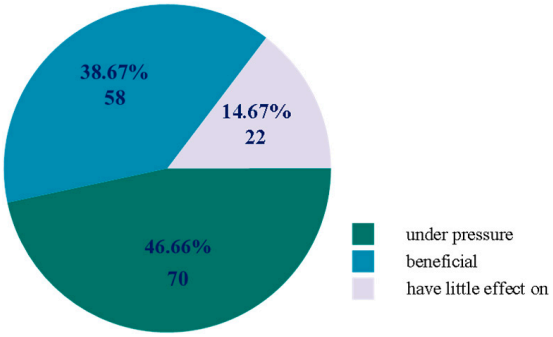


Figure 3. The perceptions of the impact of "Peak carbon and carbon neutrality" on businesses.

Although the carbon trading market is running steadily, it is still in its early stages, and its activity needs to be increased. The trading and guarantee mechanisms are swtill being continuously developed and improved. In this context, the vast majority (84.67%) of surveyed power generation enterprises hope to participate in carbon trading (Figure 4), but there are still some non-key emission units that are not very concerned about emission control policies and trading processes under the dual-carbon targets.

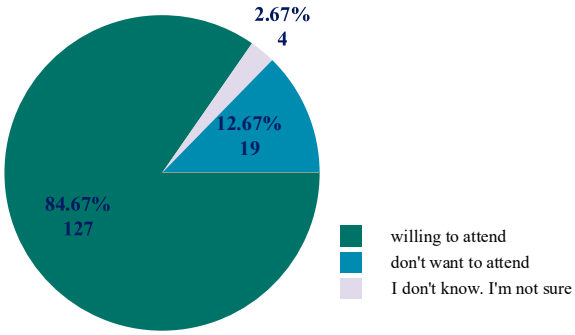


Figure 4. Willingness of companies to participate in carbon trading.

In addition to the companies that have already joined or are planning to join, nearly 50% of the surveyed enterprises indicated that they may join within the next three years (by

2025), with only 0.7% stating that they will not join carbon trading in the future (Figure 5). This indicates that the comprehensive participation of power generation enterprises in carbon trading is an inevitable trend in the future, and it is speculated that most power generation enterprises will participate in carbon trading in China before the national carbon peak is achieved (planned for 2030).

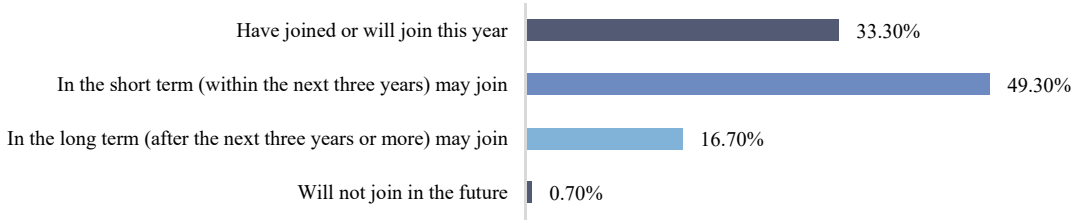


Figure 5. Enterprises' willingness to join carbon trading in the future.

The attitude towards the carbon financial market is relatively pessimistic. Forty-nine surveyed enterprises that have already conducted related work and those preparing or planning to do so generally believe that financial institutions have limited support for green projects and that the related financial market is not well developed. This viewpoint may cause companies on the sidelines to prolong their observation and preparation period, slowing down their entry into the carbon financial market.

(2) Analysis of the Current Status of Carbon Asset Management in Surveyed Enterprises

Of the surveyed enterprises, 37.33% have established dedicated carbon asset management organizations/departments. Of the surveyed enterprises, 30% have no related plans, with many being non-key emission enterprises, while the remaining enterprises have collaborated with third-party professional organizations (Figure 6).

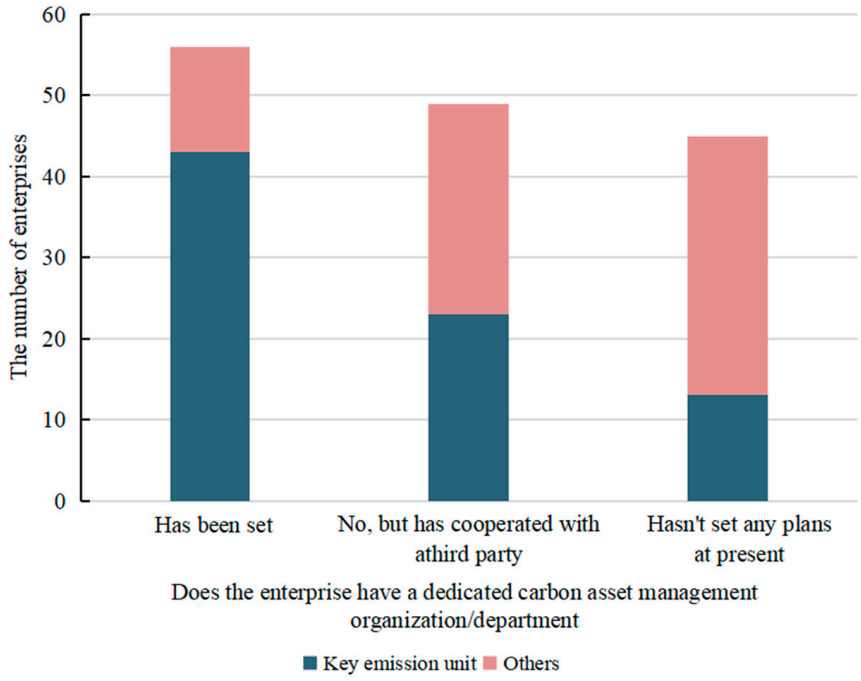


Figure 6. Enterprises' carbon asset management organization establishment.

There were certain differences in the preparation of various carbon management work system documents within the surveyed enterprises. Of the surveyed enterprises, 79.33% indicated that they already have institutional documents for carbon emission reduction work, which performed the best among the various works mentioned in this article. The

surveyed enterprises with institutional documents for carbon inventory, carbon trading, and carbon finance work accounted for 62.67%, 52.66%, and 44%, respectively. At the same time, the proportion of enterprises with institutional documents for all four works was 12.66%, indicating a relatively low level. Regarding the preparatory work for building a carbon asset management system and participating in carbon trading, the current status and policy research of the carbon trading market were the best. The preparation for carbon inventory work came next. In comparison, the surveyed enterprises are more in a state of marginal observation and preparation in terms of innovation and the application of carbon financial tools, with a higher number of enterprises in the preparation and planning stage (Figure 7).

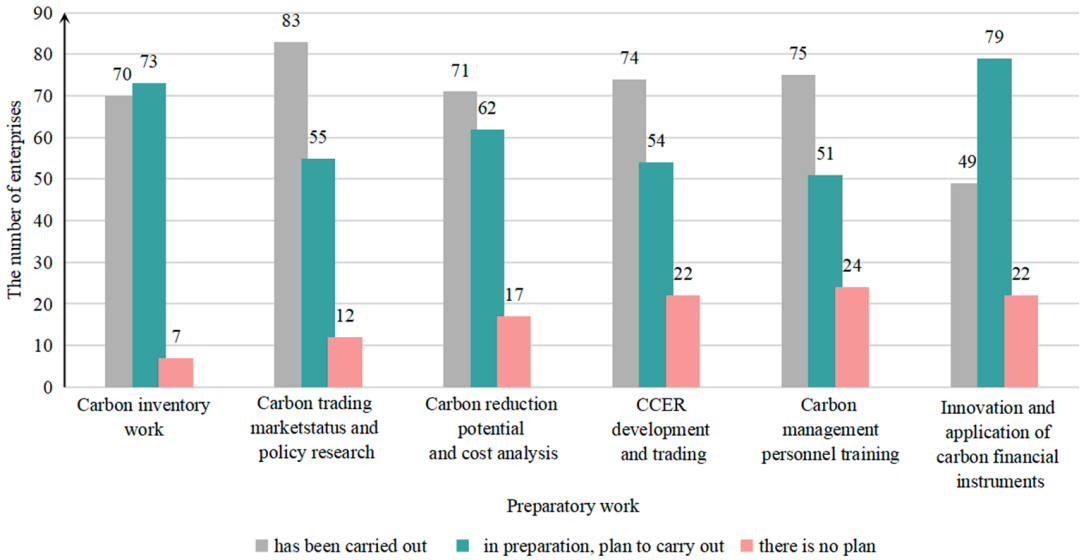


Figure 7. The preparation statuses of enterprises in various aspects of participating in the carbon emission trading system.

The clustered bar chart below (Figure 8) shows the proportion of the annual investment in emission reduction actions compared to the annual revenue for each company's planned carbon reduction method. In terms of planned carbon reduction methods and budgets, the majority (68.7%) of the surveyed power generation enterprises invest 20% or less of their annual revenue in emission reduction actions. Almost all the surveyed enterprises have their own carbon reduction plans and tend to focus on achieving carbon reduction through equipment and technology upgrades. The distribution of emission reduction budgets for different methods is generally the same, with the majority being 0–20% of the company's annual revenue.

The self-evaluation of the actual completion status of several works such as carbon inventory, power generation production, carbon trading, carbon emission reduction, CCER project development, and carbon management personnel training by the surveyed enterprises in 2021 is shown in the following graph (Figure 9). Most surveyed power generation enterprises had their own production and emission reduction plans, but more than 50% of the enterprises had no plans for the other works. The planned participation in carbon trading was relatively low. Following the launch of the national carbon market, the trading activity remained high in the early stages but gradually weakened, then heated up again at the end of the period, ultimately closing at a price 13% higher than the opening price [34]. The "There is no plan" status was most common for CCER work, and the average level of this work was the worst. The average level of carbon emission reduction work was relatively good, but the number of companies stating "unable to achieve expectations, needs help" was the highest.

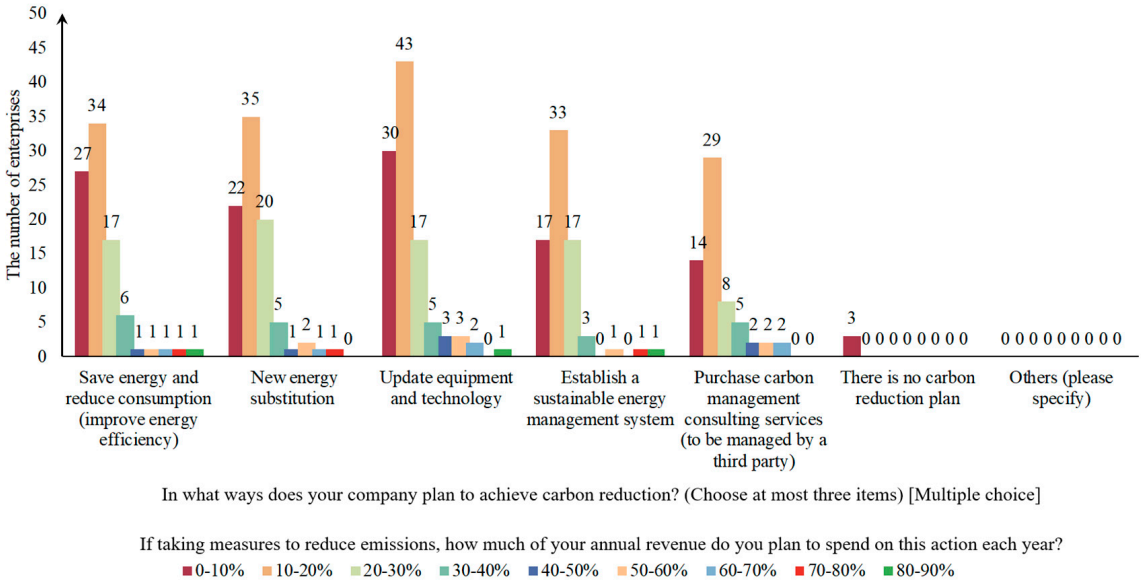


Figure 8. Clustered bar chart showing the planned carbon reduction methods and the proportion of the annual investment in emission reduction actions to the annual revenue.

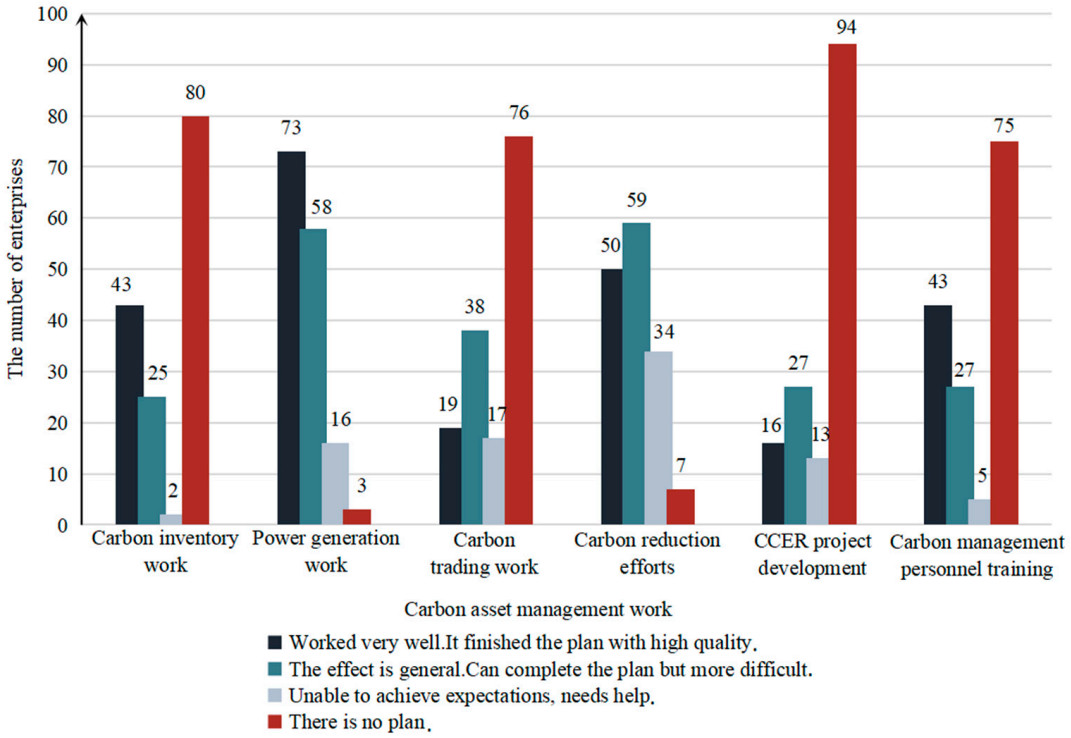


Figure 9. Completion status of various works in carbon asset management in 2021.

The most commonly reflected difficulties encountered by power generation enterprises in carbon emission reduction in 2021 were a slow pace of technological updates and increasing emission reduction costs (Figure 10). In response to these difficulties, 97.33% of the surveyed power generation enterprises stated the need for services and assistance from third-party professional organizations, including those that have established dedicated carbon asset management organizations/teams. The most needed assistance (66.67%) was in "carbon emission reduction potential analysis and emission reduction work", with little difference in the other service areas.

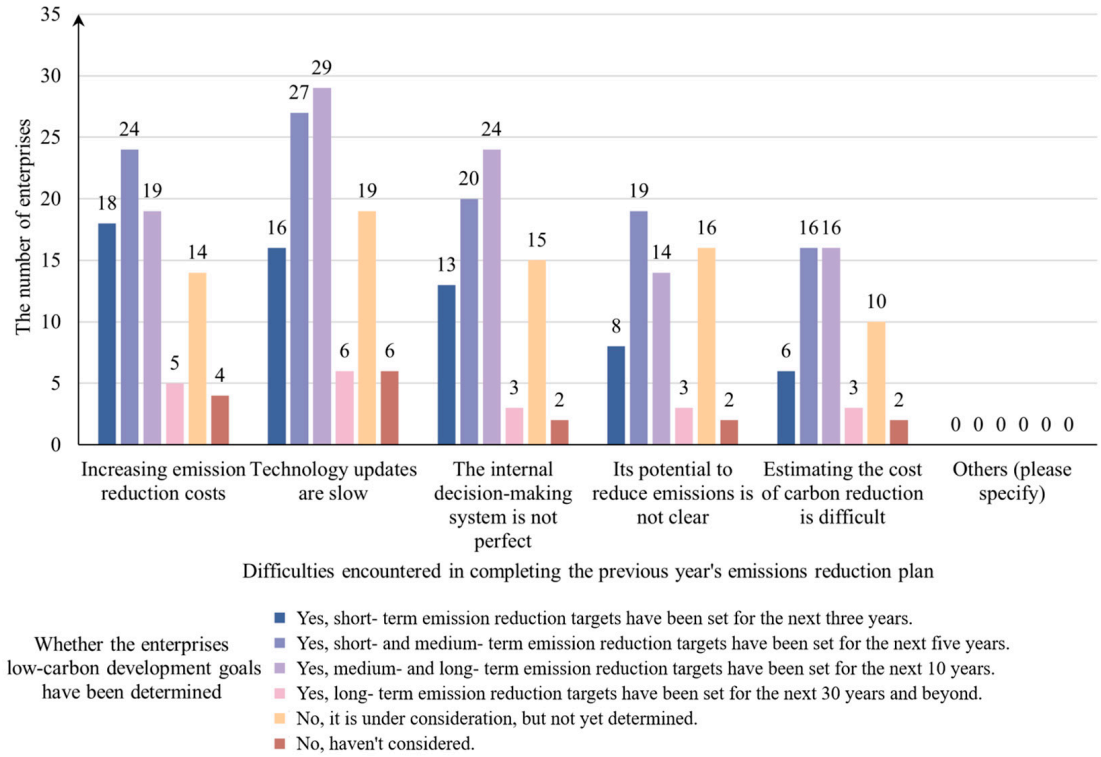


Figure 10. Difficulties encountered by enterprises in achieving emission reduction plans in 2021.

Out of 150 valid responses, 127 provided suggestions and requests for help related to low-carbon development. These can be roughly categorized into 9 types: 39 related to the development of new methods, which is the largest proportion, including the hope for national assistance in new energy technology, sharing emission reduction technology, and support from universities; 20 related to professional talents, training, and guidance; 10 related to financial support; 19 related to policy subsidies, incentives, and reward policies; 8 related to tax incentives and exemptions; 7 related to publicity; 7 related to reducing emission reduction costs; 6 related to the development of a sound carbon financial market and support from the financial industry; and 13 other types, such as the hope for more favorable project loan rates from banks.

(3) Analysis of the differences in the implementation and effects of various works

There are differences in the preparation of carbon management works among samples with different characteristics.

First, there are differences in the preparation of works among different enterprises. According to the independent sample *t*-test results (Table 2: "Already implemented", "Preparing, planning to implement", and "No plan" options, valued as 1, 2, and 3), it can be seen that key emission units are more fully prepared for carbon inventory, the current status and policy research of the carbon trading market, CCER development and trading, carbon management personnel training, and innovation and application of carbon financial tools compared to non-key emission units. There are no significant differences among all the surveyed enterprises in terms of their carbon emission reduction potential and cost analysis work.

Using a one-way analysis of variance (ANOVA) (the analysis and multiple comparison results are shown in Appendix B, Table A1), it was found that the preparation for CCER development and trading is influenced by several factors. The influence and multiple comparison results are shown in the inequality of the serial number in the table: enterprises approaching carbon neutrality and those with higher annual comprehensive average energy consumption are more prepared for this work. Companies that have established clear carbon management goals are more prepared for this work compared to power generation

enterprises that do not consider setting goals, and companies with closer and more specific goals are more prepared. Enterprises with their own dedicated carbon asset management organization/department are more prepared for this work compared to those that only collaborate with third-party organizations.

Table 2. Differences in preparation for key emission units (results of independent sample *t*-test).

	Whether It Is a Key Emission Unit	N	Average Value	Standard Deviations	t	Conspicuousness Sig
Carbon inventory work	Yes	79	1.43	0.523	−3.437	0.001
	No	71	1.75	0.603		
Carbon trading market status and policy research	Yes	79	1.41	0.494	−2.437	0.016
	No	71	1.66	0.755		
Carbon reduction potential and cost analysis	Yes	79	1.56	0.594	−1.57	0.119
	No	71	1.73	0.755		
CCER development and trading	Yes	79	1.14	0.445	−13.781	0
	No	71	2.23	0.513		
Carbon management personnel training	Yes	79	1.51	0.638	−2.705	0.008
	No	71	1.83	0.81		
Innovation and application of carbon financial instruments	Yes	79	1.62	0.626	−4.065	0
	No	71	2.04	0.642		

The factors influencing the preparation for the current status and policy research of the carbon trading market and the carbon emission reduction potential and cost analysis, as well as the multiple comparison results, are also reflected in Table A1 in Appendix B. It can be observed that power generation enterprises with their own dedicated carbon asset management organization/department are more prepared for the above two works compared to those that only collaborate with third-party professional organizations.

Furthermore, there are differences in the completion effects of various works among different enterprises. According to the use of one-way analysis of variance (ANOVA) (part of the analysis and multiple comparison results are shown in Appendix B, Table A2), power generation enterprises with their own dedicated carbon asset management organization/department had significantly better performance in carbon trading and carbon emission reduction works in 2021 compared to those without a dedicated carbon asset management organization/department, and those that only collaborated with third-party professional organizations. They also had better performance in carbon inventory work compared to enterprises that only collaborated with third-party professional organizations.

The establishment of low-carbon development goals by enterprises also had an impact on the carbon management effectiveness in 2021. In terms of carbon emission reduction work in 2021, enterprises with short-term, low-carbon development goals had relatively better completion effects.

(4) Correlation of the completion effects of various carbon management works in the surveyed enterprises

Based on the correlation analysis of the completion effects of various carbon management works in 2021 for power generation enterprises shown in Table 3, it can be concluded that in terms of the completion effects shown in the table, carbon inventory work is positively correlated with all other works in the table. Most of the works within the system are significantly correlated with each other, indicating that the establishment of a system has a mutually reinforcing effect on the implementation of various works and confirms the positive significance of the establishment of a system for the effective implementation of each work.

Table 3. Correlation analysis of the completion of carbon asset management in power generation enterprises in 2021.

Variable	Relativity	Carbon Inventory	Power Generation	Carbon Trading	Carbon Emission Reduction	CCER Project Development	Carbon Management Personnel Training
Carbon inventory	Pearson correlation	1					
Power generation	Pearson correlation	0.196 *	1				
Carbon trading	Pearson correlation	0.357 **	0.127	1			
Carbon emission reduction	Pearson correlation	0.434 **	0.355 **	0.350 **	1		
CCER project development	Pearson correlation	0.234 **	0.123	0.436 **	0.138	1	
Carbon management personnel training	Pearson correlation	0.300 **	0.263 **	0.147	0.439 **	0.138	1

* indicates that at the 0.05 level (two-tailed), the correlation was significant; ** indicates that at the 0.01 level (two-tailed), the correlation was significant.

3.5. Factors Affecting Actual Carbon Management Effectiveness

This section analyzes the impact of the preparation of various carbon trading-related works on the actual carbon management effectiveness of enterprises by constructing a multiple regression model. This improves the understanding of the different degrees of importance of the various works for the operation of the system and provides guidance for power enterprises in identifying the key points and directions when building a carbon management system. It also serves as a basis for providing suggestions to the government and enterprises for improving the effectiveness of carbon management. Therefore, variables that can reflect the actual carbon management effectiveness of enterprises were chosen as the dependent variables, while variables reflecting the preparation of various carbon trading-related works were chosen as the independent variables. The scoring criteria for the explanatory variables were set according to the table shown in Table 4.

Table 4. The basis for assigning carbon management work readiness.

Order	Level	Assign Points
1	Has been carried out.	100.00
2	In preparation, plan to carry out.	66.67
3	There is no plan.	33.33

Based on the sample data, the dependent variable was determined to be the score of the effectiveness of carbon asset management work in enterprises in 2021. This score was obtained by assigning scores to the completion effects of carbon inventory work, carbon trading work, carbon emission reduction work, CCER project development, and carbon management personnel training, as shown in Table 5, and then using the subjective weighting method to determine the weights, which were ultimately multiplied and summed.

In this analysis, the subjective weighting method was used to determine the weights of the various works constituting the dependent variable. Surveys were distributed to industry experts, and the average opinions of the experts were compiled to form a judgment matrix (Table 6). The weights of the various works were then calculated using the analytic hierarchy process—the eigenvalue method. The calculation results are shown in Table 7

(rounded to four decimal places). The consistency ratio (CR) of the analytic hierarchy model established in this paper is 0.003, as confirmed by consistency testing.

Table 5. Classification basis for the completion effect of the carbon management work.

Order	Level	Assign Points
1	Worked very well, it finished the plan with high quality.	100.00
2	The effect is general, can complete the plan but more difficult.	75.00
3	Unable to achieve expectations, needs help.	50.00
4	There is no plan.	25.00

Table 6. Judgment matrix for determining weights using the subjective weighting method.

	Carbon Inventory	Carbon Trading	Carbon Reduction	CCER Project Development	Carbon Management Personnel Training
Carbon inventory	1	1.367	0.833	3.4	2.1
Carbon trading	0.732	1	0.717	2.167	1.867
Carbon reduction	1.2	1.395	1	3.1	2.6
CCER project development	0.294	0.462	0.323	1	0.9
Carbon management personnel training	0.476	0.536	0.385	1.111	1

Table 7. Determines the results of the weights using the subjective empowerment method.

Work	Carbon Inventory	Carbon Trading	Carbon Reduction	CCER Project Development	Carbon Management Personnel Training
w_j	0.27491	0.21012	0.30423	0.09469	0.11605

Based on the above data processing results, the actual carbon management effectiveness R of enterprises in 2021 was calculated using Equation (1):

$$R = \sum_{n=1}^{4} s_n \times w_j \quad (1)$$

R: actual carbon management effectiveness of enterprises in 2021; s_n: corresponding scores in the effectiveness scoring table; and w_j: corresponding weights.

According to the above calculation method, the results of the dependent variable, the actual carbon management effectiveness score of surveyed enterprises in 2021, were calculated and grouped with a 25-point interval, as shown in Table 8.

Table 8. Distribution of actual carbon management effectiveness scores of surveyed enterprises in 2021.

Grade	Frequency	Frequency (%)
25–50	58	39%
50–75	50	33%
75–100	42	28%
Total	150	100%

Using the actual carbon management effectiveness of enterprises in 2021 as the dependent variable and the scoring results of various carbon management preparations in enterprises as the influencing factors, a linear regression model was constructed using SPSS

for analysis. The adjusted R-squared value was 0.789 (Table 9), indicating that the selected factors can explain around 80% of the variance in the dependent variable. The Durbin–Watson statistic for the model was 2.003, close to 2 (Table 9), indicating independence among the samples.

Table 9. Model Summary b.

Model Summary b				
R	**R^2**	**Adjusted R^2**	**Error in the Standard Estimation**	**Durbin–Watson**
0.892 a	0.796	0.789	9.0557898	2.003

a Predictor variables: (constant) innovation and application of carbon financial tools, training of carbon managers, carbon emission reduction potential and cost analysis, carbon inventory work, CCER development and trading, carbon trading rules, market status, and policy research. b Dependent variable: the work effect of carbon asset management.

In the model's multicollinearity statistics (Table 10), the VIFs were all between 1 and 1.4, indicating the absence of multicollinearity between the variables. Additionally, the standardized residuals of the model approximately follow a normal distribution (Figure 11). Based on these findings, the model meets the prerequisites for linear regression analysis and is effective.

Table 10. Regression Model Coefficients [a].

	Unstandardized Coefficients		**Standardization Coefficient**	**t**	**Significance**	**Collinearity Statistics**	
	B	**Standard Error**	**Beta**			**Allowance**	**VIF**
(Constant)	−35.130	4.447		−7.900	0.000		
Carbon inventory work	0.563	0.040	0.554	14.018	0.000	0.907	1.103
Carbon trading market status, and policy research	0.055	0.040	0.059	1.376	0.171	0.758	1.319
Carbon reduction potential and cost analysis	0.035	0.035	0.040	1.006	0.316	0.892	1.121
CCER development and trading	0.286	0.033	0.350	8.660	0.000	0.869	1.151
Carbon management personnel training	0.249	0.034	0.312	7.257	0.000	0.767	1.305

[a] dependent variable: the work effect of carbon asset management.

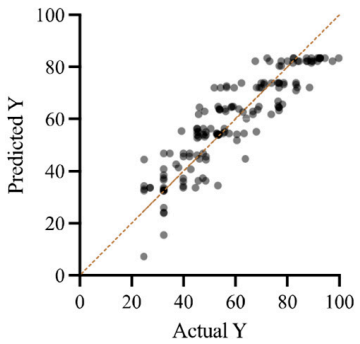


Figure 11. Predicted and actual dependent variable.

As shown in Table 10, the significances of carbon inventory work, CCER development and trading, and carbon management personnel training were all less than 0.05, indicating a significant correlation between the dependent variable, the carbon management effectiveness of enterprises in 2021, and the aforementioned works.

The beta coefficients of the aforementioned three significant influencing factors on the effectiveness of carbon asset management work are all positive. This suggests that in this model, carbon inventory work, CCER development and trading, and carbon management personnel training all have a significant positive impact on the carbon management effectiveness of power enterprises. Based on the analysis results, we can approximately derive the linear regression equation for this data environment as Equation (2):

$$R' = -35.130 + 0.563 \times s_1' + 0.286 \times s_4' + 0.249 \times s_5' \quad (2)$$

R′: the estimated value of the actual carbon management effectiveness of enterprises in 2021; s_n': corresponding scores in the preparation work scoring table.

The fit between the actual and predicted dependent variables (Figures 11 and 12) is good, making the model relatively reliable, based on the support from this survey data.

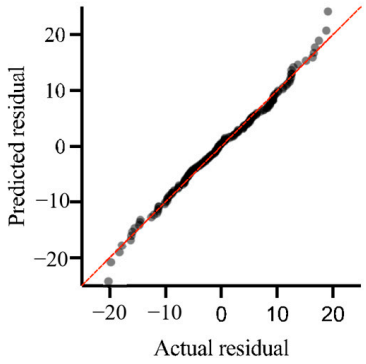


Figure 12. Predicted and actual residual.

According to the data analysis above, the key factors affecting the carbon management effectiveness of power enterprises are the planning and implementation of carbon inventory work, CCER development and trading, and carbon management personnel training. Among these, the impact of carbon inventory work is the most significant. Combined with the previous differential analysis and correlation analysis, it is found that the influencing path is as follows: the characteristics (such as whether it is a key emitting unit), the annual comprehensive energy consumption, whether there is a dedicated carbon management department/team, and the distance and specificity of low-carbon development goals affect the actual carbon management effectiveness of enterprises by influencing key factors such as carbon inventory, CCER development, and the allocation and training of carbon management personnel, thereby affecting the actual carbon management effectiveness of enterprises. Furthermore, the completion effects of the five works in the system are almost all positively correlated, confirming the important and positive significance of having a dedicated carbon management team and building a carbon management system for enterprise emission reduction and low-carbon development.

4. Summary of Carbon Management Issues in Power Enterprises

Based on this investigation and analysis of the current situation of carbon asset management in Beijing's power enterprises, combined with the authors' definition of carbon assets and the framework of carbon asset management systems for power enterprises mentioned earlier, the following problems in carbon asset management for power enterprises are summarized:

(1) Incomplete coverage of carbon inventory: The overall preparation and implementation of carbon inventory work among the surveyed enterprises are relatively good compared to the other mentioned carbon management tasks in this document. However, half of the surveyed enterprises still do not possess relevant system documents for carbon inventory. This is an important safeguard and reference in carbon as-

set management work, which affects the effectiveness of carbon management for enterprises. Currently, the coverage is still not comprehensive.

(2) Low planning for carbon trading: Power enterprises have a strong willingness to participate in trading. According to the survey, it is expected that a large portion of enterprises will join carbon trading within the next three years, and in the longer term, all power enterprises may eventually join carbon trading. However, the plans for carbon trading are unclear. In 2021, carbon trading exhibited obvious peak values and long tails, and the carbon price could not truly reflect the market supply and demand [35]. Not only is the planning for trading weak, but the preparation and completion of trading work also vary significantly among different enterprises, especially between control-emission and non-control-emission enterprises.

(3) Lack of carbon management systems and personnel: The preparation of enterprises in terms of carbon management systems is not ideal, with only 12% of the surveyed enterprises having all the required system documents for the mentioned tasks. Furthermore, there is a shortage of dedicated carbon asset management personnel in power generation enterprises in Beijing, with nearly half of the surveyed enterprises having almost no dedicated personnel for carbon asset management; the carbon management work is mostly handled by part-time staff from other business departments, such as finance [36]. This could be due to the scarcity of existing professional talent in carbon management and the cost of hiring dedicated personnel.

(4) Difficulty in achieving carbon emission reduction targets: The preparation and implementation of emission reduction work reflect no difference between control-emission and different energy consumption levels of enterprises, indicating that, against the backdrop of reducing carbon costs and increasing carbon trading chips, power generation enterprises in Beijing generally attach importance to emission reduction work. In 2021, most power generation enterprises in Beijing had carbon emission reduction plans, with the annual carbon reduction budget for most enterprises being roughly between 10% and 20% of annual revenue. However, many enterprises find it challenging to meet their reduction targets. The high cost of emission reduction and slow technological updates are the two main reasons for the currently low efficiency and challenging nature of emission reduction for enterprises.

(5) Low understanding and application of carbon financial tools: The current Chinese carbon financial market generally suffers from inadequate legal and institutional systems, with few financial market products and uncertain returns on low-carbon industries. Power enterprises' exploration and trust in carbon financial tools are still insufficient. Coupled with the scarcity of professional talent, this has led to a generally low level of understanding and insufficient preparation for joining the carbon financial market among power enterprises. Many power enterprises are still in the understanding stage, expressing plans to engage, but only a very small portion have actually initiated such efforts.

5. Enterprise Carbon Asset Management System Construction

The following are the steps and key focus areas for constructing the carbon management system in power enterprises, based on the framework of the carbon asset management system and the conclusions of the survey analysis.

5.1. Enterprise Carbon Asset Inventory

(1) Enterprise Self-Planning and Positioning

The first and foremost preparatory work for enterprises in constructing a carbon asset management system is to establish reasonable development goals based on environmental conditions and their own operational situation. Enterprises' self-positioning can generally be divided into four types: compliance-oriented, profit-oriented, strategic development-oriented, and low-carbon publicity-oriented (Table 11 shows the main differences in carbon management for the three common types of enterprises). Enterprises should promptly establish carbon reduction targets in accordance with their own positioning and important policy timelines.

Table 11. Characteristics of different emission reduction types of enterprises.

	Compliance Type	Trading Profit-Making	Strategic Development
Primary objective	Compliance performance	Compliance performance, carbon asset appreciation profit	Long-term low carbon development
Trade enthusiasm	Lower	Higher	Higher
The attitude towards carbon trading	Means of performance, transaction on demand	The means of profit is a form of business	Strategic needs
Carbon financial tools	Almost no use	Try to use	Lead the innovation, skilled use
Scope	Multi-numerical control enterprise	Actively control and order enterprises	Large group enterprises

(2) Establishing a Carbon Inventory System

Enterprise carbon inventory refers to the investigation of greenhouse gas emissions sources, emission processes, and emission volumes resulting from the production activities and behaviors of an enterprise within a certain time and space. The survey found that the implementation of carbon inventory work is not only a key factor affecting the effectiveness of carbon management in power enterprises, but also that its effectiveness is positively correlated with all other carbon management work. The workflow of carbon inventory work in power generation enterprises is summarized in Figure 13. The scope of carbon inventory calculation usually covers the entire jurisdiction of the enterprise, and the emission sources can be divided into two major categories: fixed combustion emissions directly generated by power generation enterprises for power production and non-fixed combustion emissions directly generated by the non-power generation business activities of the enterprise. Enterprises should trace greenhouse gas emissions from various emission sources and collect data accordingly. Existing data collection methods include the direct installation of greenhouse gas emission monitoring devices and obtaining data through calculations. Many scholars have conducted research on calculation methods, such as using the mass balance method and emission factor method, to study the model tools and indicator systems for calculating carbon emissions [37]. The report formed from the inventory discloses the carbon information of the enterprise and provides a reference for the enterprise to formulate a low-carbon development strategy, thereby promoting the optimization of the energy structure in power generation enterprises and facilitating the transition to low-carbon.

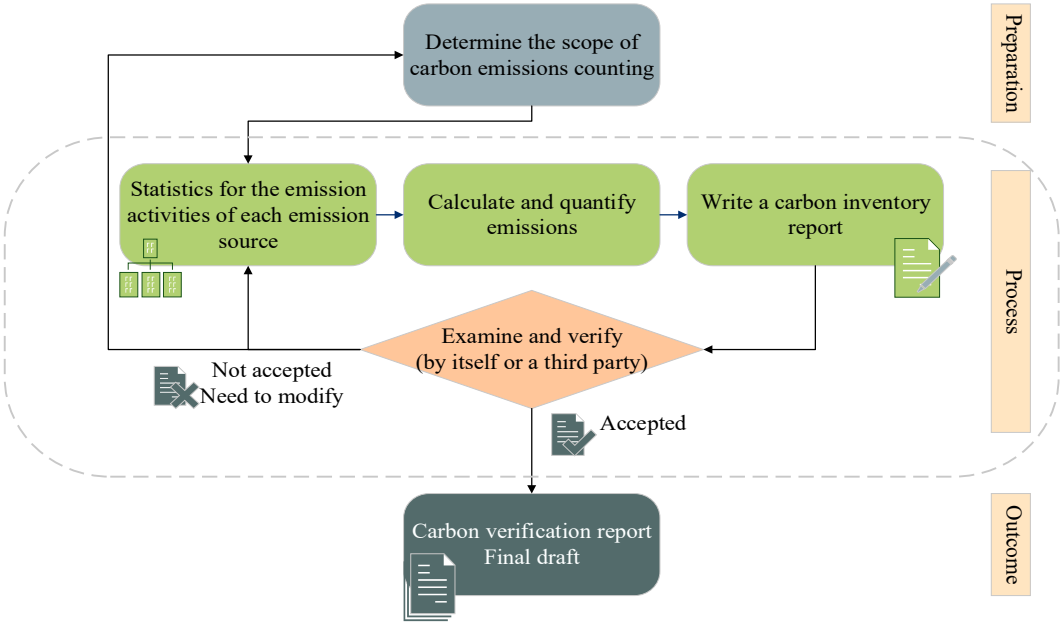


Figure 13. The process flowchart of carbon inventory in power generation enterprises.

5.2. Establishing a Carbon Management Mechanism

(1) Determine the carbon management organizational structure and actively train personnel

Carbon asset management involves four business modules: carbon inventory, carbon trading, carbon emission reduction, and carbon finance, as well as training for carbon management personnel. It is a highly specialized task. Therefore, efficient corporate carbon management requires a professional carbon asset management team and the clear division of labor. The survey results also fully demonstrate that the presence of a dedicated carbon management team has a significant impact on the effectiveness of carbon management. Enterprises can consider organizing the structure according to the four different types of carbon business, establishing a work leadership group and a department for carbon emission management and execution (organizational structure and functions as shown in Figure 14), establishing a top-down coordination mechanism and feedback mechanism, and designing supportive financial management and supervision mechanisms. The main business of each functional unit is also influenced by the low-carbon development positioning and stage of the enterprise.

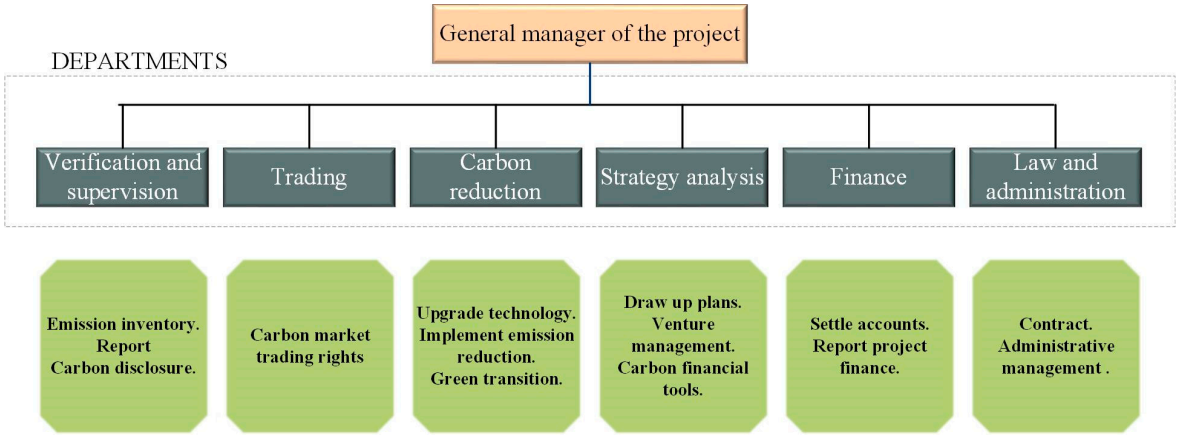


Figure 14. The organizational structure of carbon management in power generation enterprises.

(2) Formulate the enterprise's carbon asset management system

The establishment of a carbon asset management system and framework can standardize and streamline the management of carbon emissions in enterprises and is the fundamental path for enterprises to achieve carbon peaking. The enterprise carbon asset management system should include at least four basic tasks: carbon accounting methods, carbon trading management mechanisms, carbon emission cost analysis and emission reduction systems, and carbon asset investment management systems, to guide the implementation of emission control, carbon asset management and trading, and emission reduction work in various departments of the enterprise and establish feedback and supervision mechanisms. Currently, many enterprises have emission reduction systems, but the coverage of the other three systems is not ideal, with only one-tenth of the enterprises having all of the above systems. The formulation of the carbon management system should follow the "top-down" principle, first establishing general rules for enterprise carbon emission control management at the top level, and then establishing the organizational structure, division of labor, coordination mechanisms, and target assessment systems for the group's carbon management business in carbon accounting, carbon trading, carbon emission reduction, and carbon investment [38]. Specific work norms and evaluation methods for detailed statistical accounting systems, carbon work implementation methods, and technical details, as well as assessment and evaluation systems, investment management methods, etc., should be established. At the same time, there should be comprehensive and reliable monitoring and management.

5.3. Establishing a Carbon Trading System

(1) Mastering Trading Rules and Market Dynamics

Before participating in trading, power generation enterprises must be familiar with the detailed deployment and trading rules of the national carbon market, understand important time points in achieving carbon neutrality, be familiar with the performance process and deadlines of important events, and master trading rules. Since carbon market prices are significantly influenced by factors such as fossil fuel prices, economic conditions, and even carbon prices in other regions or countries such as the EU [39], power generation enterprises should actively pay attention to the dynamics of domestic and international carbon emissions trading markets and other green markets, and grasp stable and reliable trading information channels to remain sensitive to carbon price changes in order to adjust trading behavior and strategies in a timely manner.

(2) Determining the Trading Demand and Trading Strategies

In the long-term trading market, it is predicted that carbon prices will generally trend upwards for a long period in the future, but phenomena such as concentrated trading in the first delivery period occurred within a week after the opening and at the end of the year, indicating that the carbon market has the characteristics of a high short-term risk and a low long-term risk. Enterprises should, in light of the characteristics of the carbon market, be familiar with the characteristics of trading commodities, fully grasp the value of the right to choose in carbon emissions allowances, and leverage their market value or use value based on their own needs and characteristics [40]. In addition to comparing overall and systematic trading principles, enterprises can adjust short-term trading strategies based on their own predictions of carbon price fluctuations, such as "selling high and buying low", "momentum trading", "oscillating trading", "plate trading", etc., in line with the overall goal of low-carbon development and stage goals to enhance the planning of trading.

(3) Determining Trading Products and Methods

Due to the limited variety of existing trading commodities, there are currently no abundant derivatives or future products in the market. Enterprises should pay attention to products that may be added to the market in the near future and reasonably choose trading product structures based on changes in demand and product scope. In addition, power generation enterprises need to balance power generation and trading volumes to reduce costs and increase emission reductions, thereby entering a virtuous cycle [41]. In addition to direct participation in trading, enterprises can also entrust a certain proportion of quotas to professional institutions to obtain committed returns. This method has been popular in some pilot areas due to its ability to avoid risks, but it is also influenced by policy uncertainties and the risk of selecting institutions. Faced with a variety of trading methods, strategic choices, and different enterprise situations and development strategies, the personnel responsible for carbon trading management should analyze the trading needs of the enterprise, predict the costs and benefits of different products and trading methods, and provide timely feedback and risk control during trading.

5.4. Establishing a Carbon Emission Reduction System

(1) Analysis of the Carbon Emission Reduction Potential and Costs

After the introduction of the carbon market, the marginal costs of emission reduction for different power generation methods may change, and as a result, the order of dispatch may be altered [42]. Power generation enterprises should quantify the actual generation costs and marginal costs of units under the influence of carbon costs and adjust production plans and even power generation structures as needed. The effectiveness of carbon emission reduction work is the main source of an advantage for enterprises in trading and is also the main cost of managing carbon assets for enterprises. However, this investment will not only consume enterprise resources but can also compensate for the costs incurred

by the enterprise in the early stages due to environmental protection in the long run and may even generate corresponding benefits [43]. Before carrying out carbon emission reduction work, it is necessary to comprehensively understand the current status of the enterprise through analyzing changes and unit product energy consumption and evaluating the current emission status and energy utilization efficiency of the enterprise. Compare the evaluation results with industry standards and advanced levels at home and abroad to identify carbon advantages and issues and improve the carbon reduction efficiency and space.

(2) Developing and implementing a Carbon Emission Reduction Plan

Based on this in-depth analysis of emission reduction potential and cost-effectiveness, it is imperative to construct a carbon emission management network and refine emission reduction strategies. Emission reduction target setting can be a flexible strategy, which can be planned from the macro level (top-down) and implemented from the micro level (bottom-up) [44]. Existing research provides a multi-level framework for carbon emission reduction, covering the evolution path of enterprises from static game to principal-agent to multi-party game [45], and enterprises need to adjust flexibly, according to their own stages. Figure 15 shows the general process of enterprises' carbon emission reduction programs and timely feedback.

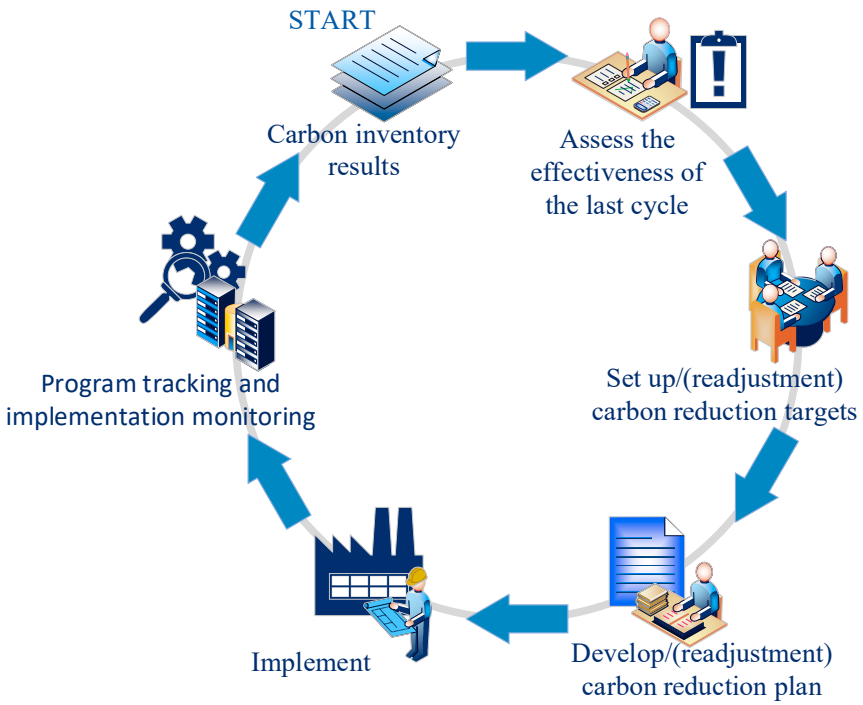


Figure 15. Flowchart of carbon emission reduction plan formulation for power generation enterprises.

Power generation enterprises should take a two-pronged approach to the emission reduction path. One is to accelerate capacity iteration, eliminate inefficient coal-fired units, and actively integrate into the renewable energy system, especially by utilizing the advantages of wind energy and other resources to increase the proportion of clean energy generation [46,47]. Second, focus on technological innovation and promote comprehensive progress in energy efficiency improvement, emission reduction processes, greenhouse gas management, and carbon sink technologies through R&D support [48]. Enterprises should also focus on advanced technologies for cost reduction, such as power storage, to help the transition to an all-renewable energy system [49]. Together, these measures will contribute to a significant increase in emission reduction benefits.

5.5. Constructing a Carbon Financial System

(1) The Development and Reservation of CCER Projects

CCER refers to the nationally verified voluntary emission reduction credits. As of April 2021, there were a total of 2871 publicly announced CCER approved projects, 861 filed projects, and 254 projects with filed emission reduction credits. The price of CCER fluctuates between 20–30 yuan/ton [50]. CCER, as a supplementary mechanism for quotas, can be used to offset a small part of the quotas that key emitting units need to pay, helping with compliance. Although the application of CCER projects was suspended in 2017, the resumption of CCER projects is the general trend. Figure 16 describes the main process of CCER project development and the responsible parties at each stage.

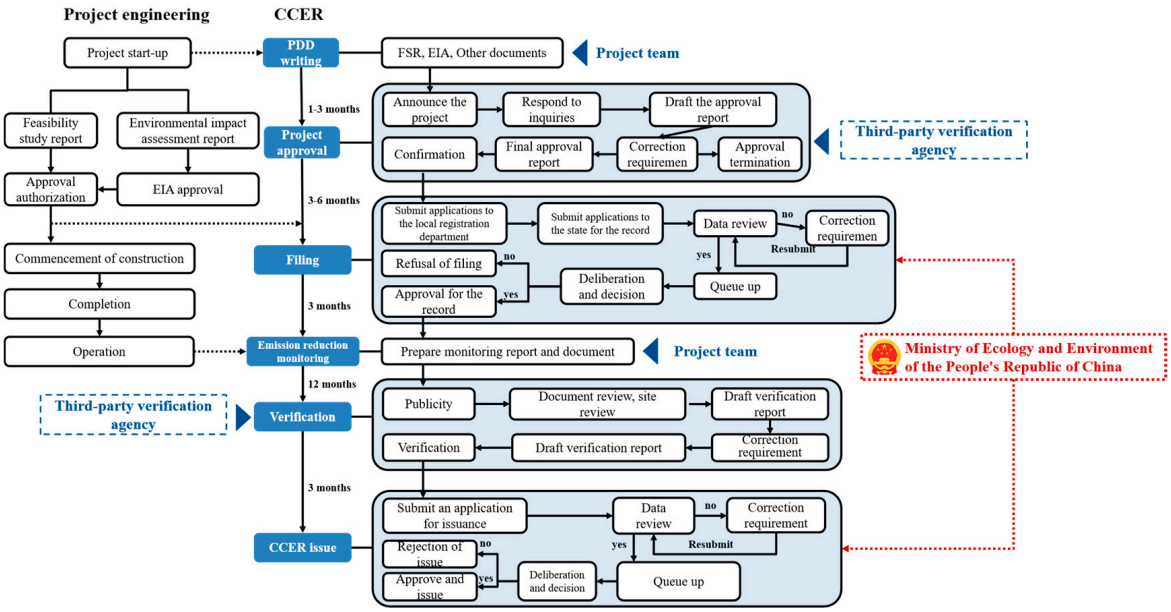


Figure 16. Flowchart of the process for power generation companies to develop CCER projects.

Considering the unequal lateral carbon compensation caused by regional interactions and internal differences is an effective method to achieve carbon reduction and harmonious regional development [51]. Power generation enterprises can leverage their industry's competitive advantages and location benefits to consider developing clean energy generation projects such as wind power and hydropower. However, the developmental cycle of CCER projects is lengthy, typically taking 6–8 months from initiation to the final realization of filed emission reduction credits [44] and is also susceptible to policy uncertainties, posing carbon risks. Nevertheless, once the emission reduction credits are secured, they offer long-term competitiveness. Power generation enterprises should carefully consider their own situation and make decisions that are suitable for their own circumstances, preparing for the resumption of CCER approval.

(2) Functions and roles of carbon financial tools

Carbon financial tools can be broadly divided into two categories: native tools and derivative tools. Native tools are the basic carbon financial instruments, and for the existing carbon market in China, they include carbon emission allowances and nationally verified voluntary emission reductions (partially). Carbon financial derivative tools, such as carbon forwards, carbon futures, carbon options, and carbon swaps, are specialized trading categories of carbon financial instruments, with returns derived from the performance of certain financial elements. Currently, China's supply chain carbon finance only includes carbon bonds, which, although established relatively late, have developed rapidly and are now beginning to take shape [52]. China is also contemplating the launch of carbon funds, with representative examples being the China Clean Development Mechanism Fund and

the China Green Carbon Fund [53]. Domestically, there are three types of carbon-pledged financing models: mixed financing based on enterprise fixed assets and expected carbon revenue, financing based on expected enterprise carbon revenue, and financing based on government-allocated carbon emission rights [54].

(3) Participate in carbon financial innovation to increase the value of carbon assets

The national unified carbon market has just begun, and there is great potential in the financial and brokerage markets. Both power enterprises and financial institutions have a lot to do. They can help companies lock in carbon costs and revenues in advance, transfer risks, optimize the allocation of carbon assets, and offset some of the impacts of inflation. Currently, spot commodities dominate the national carbon trading market in China, but the carbon market is bound to quickly attract attention from the financial industry, and the financial potential of carbon products will be explored. The introduction of carbon financial investment products is only a matter of time. As one of the first batch of trading objects included in the carbon market, power generation enterprises should learn about the development and flow processes of international carbon financial products, make preparations, actively innovate, fully explore the unique functions and roles of financial products, and increase the value of carbon assets.

5.6. Policy and Institutional Level Recommendations

To enhance the predictability of trading plans, coordinate different carbon products and electricity product markets and improve the carbon market mechanism. The relevant market mechanisms of the national carbon market in China are not mature enough, and there is a lack of overall coordination in the mechanism design between the electricity market, carbon quota market, CCER market, and other markets. In particular, the design and operation of the electricity market and the carbon market have been relatively independent. It is possible to explore the establishment of a mechanism for the mutual recognition and circulation of different types of carbon rights products such as carbon quotas, green certificates, and CCER. This can help companies reduce the carbon risks from policies and market systems, increase their participation in the carbon market, and thereby stimulate companies to actively reduce emissions.

To address the difficulty of emission reduction, xplore adjusting the pricing method of electricity to reflect changes in power generation costs. Although carbon costs and the current electricity pricing system can put pressure on power generation enterprises from a cost perspective, stimulating their low-carbon transformation, the dominance of thermal power in domestic power generation methods means that high raw material costs and carbon costs will create financial pressure on thermal power enterprises that are unable to transition quickly. Some companies may choose to reduce production to reduce carbon costs, making the supply and demand in the electricity market tighter. Adjusting the pricing method of electricity to a certain extent will reflect carbon costs and share some of the carbon costs borne by enterprises with electricity consumers. Consumers will consider their own interests and thus save electricity, helping to reduce emissions from the consumption side. From the perspective of the power supply, it is possible to increase technological investment, cultivate relevant talents, and encourage technological innovation.

Regarding the low trust and operational efficiency in the financial market, increase the scope of control for dual carbon emission reduction targets and promote the carbon financial market. In the Chinese carbon trading market, the number of trading companies operating is crucial for reducing carbon emissions [55]. Including more carbon-intensive industries other than power generation in the carbon market may stimulate the vitality of the carbon market, thereby achieving a larger scale of carbon reduction. In the Chinese carbon financial market, the lack of social attention, imperfect market mechanisms, and insufficient financial products are indeed the main factors currently limiting its development. The sustainability between the carbon market and the green financial market, which has strong development potential and profitability, is high [56]. Therefore, it is recommended that the government actively guide and provide more ways for investors to obtain profits from low-carbon

financial growth while improving the mechanism of the carbon financial market, thereby attracting more investment to accelerate the development of the carbon financial market. It is also possible to consider opening regulatory channels to other industries and social investors, enabling them to understand the carbon performance and management of enterprises and enhance market participation through regulatory participation.

6. Conclusions

The launch of the national carbon market in July 2021 directly promoted the low-carbon choices of stakeholders. For power enterprises, the carbon market brings both challenges and opportunities. Establishing corresponding institutional mechanisms for the reasonable management and use of carbon assets may achieve asset appreciation on the basis of smooth performance, helping enterprises to achieve their low-carbon development goals.

This article analyzed the attitudes of Beijing power enterprises towards China's dual carbon goals, their participation in the carbon market during the first compliance period, and the construction of their carbon management systems using literature research, questionnaire surveys, and qualitative and quantitative analysis methods. It explored the current management status of enterprises and identified the factors affecting management effectiveness. Based on the trading mechanisms, policy documents, carbon management-related literature, and survey results, it summarized the content, preparations, and construction steps that the carbon management systems of power enterprises should include. The management of carbon assets in power enterprises can be summarized by the nature of their business as comprising carbon inventory work, carbon management personnel and mechanisms, carbon trading work, carbon emission reduction work, and the development and application of carbon financial tools. The conclusions are as follows:

1. The overall carbon management effectiveness of Beijing power enterprises is generally average.

According to the model in this article, the carbon management effectiveness scores of surveyed enterprises are concentrated at the lower end (39%), with relatively few samples in the higher score range. The average score is 59.31, reflecting that the overall carbon management effectiveness of Beijing power enterprises in 2021 is average. Although a few companies have demonstrated adeptness, poor effectiveness is a more common result.

2. Regarding internal work,
    - The effectiveness of carbon inventory work is of significant importance, and its effectiveness is positively correlated with the effectiveness of other internal work within the system. The situation of carbon inventory work in power enterprises is generally good.
    - The ownership rate of carbon management mechanisms and institutional documents is low.
    - Participation in carbon trading lacks planning.
    - Carbon emission reduction work receives the most attention among the five mentioned in this article. Enterprises actively seek emission reduction strategies, but the actual emission reduction effectiveness is average, and enterprises find emission reduction to be extremely challenging.
    - The potential of the carbon financial market has not been fully explored, and power enterprises have low trust in the carbon financial market and adopt a wait-and-see attitude.

The overall systematic nature of carbon management work in the Beijing area needs improvement, and there are significant differences in the construction of the carbon management systems in terms of current carbon emissions, energy consumption, and whether the enterprise is a key emission unit.

3. Having a dedicated carbon management team and carbon asset management system is important for conducting related work.

Enterprises with dedicated carbon management teams demonstrate significantly better performance in their carbon inventory, emission reduction, carbon trading, and CCER development and application compared to those only collaborating with third-party institutions or those without dedicated carbon management teams. Most of the listed carbon management work situations in this article are positively correlated with each other, indicating that the formation of a system has a mutually reinforcing effect on the conduct of various work, and it also confirms that the formation of a system has important and positive significance for the effective implementation of each work and the development of low-carbon initiatives in enterprises.

4. Different characteristics of Beijing power enterprises, such as their low-carbon development goals, the presence of a dedicated carbon asset management department/team, and whether they are key emission units, affect the independent conduct and preparation of work such as carbon inventory, CCER development, and the allocation and training of carbon management personnel, thereby affecting the actual carbon management effectiveness of enterprises.

The analysis of the carbon management effectiveness of Beijing's electric power companies and the evaluation of the various tasks within the system provide the following insights for other countries and regions in designing and developing similar carbon management systems to contribute to the achievement of global climate goals.

① Overall assessment of carbon management effectiveness

- Other countries and regions can refer to the carbon management effectiveness evaluation system of Beijing's electric power companies to establish evaluation standards suitable for their own national conditions, which can be used to measure the carbon management performance of enterprises; by comparing the carbon management effectiveness of different regions and industries, other countries can set corresponding baselines and encourage enterprises to meet or exceed these standards.

② Specific analysis of the work within the system

- Other countries and regions should strengthen their work on carbon inventory to ensure the accuracy and completeness of data to provide a reliable basis for carbon emissions trading, strengthen the internal management mechanism of enterprises, develop institutional documents to ensure that carbon management activities are based on evidence, and improve the management level of enterprises. Although enterprises attach importance to carbon emission reduction, the actual effect is general, which suggests that other countries and regions need to strengthen their technological innovation and technology transfer to improve the efficiency of emission reduction.

③ Importance of a full-time carbon management team

- Other countries and regions can learn from Beijing's experience and encourage enterprises to establish full-time carbon management teams to improve the specialization of carbon asset management. By establishing a comprehensive carbon asset management system, enterprises can better integrate various carbon management tasks and improve the overall management effect.

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Appendix A. Investigation into the Construction, Improvement, and Existing Problems of Carbon Asset Management Systems in Power Generation Enterprises in Beijing

In order to understand the construction and improvement of the carbon asset management system of power generation enterprises in Beijing and the existing problems, and to know the power generation enterprises that may enter the carbon market in the future, this questionnaire survey is conducted. The information provided by your company will be used for qualitative analysis in academic papers and will be kept strictly confidential. Thank you for your valuable suggestions.

1. Your company name is: (optional) [Fill in the blanks] (Optional)
   _____

   I. Basic information of enterprises
2. According to the "Carbon Emission Trading Administration Measures (Trial)", is your enterprise a key emission unit? [Single choice]
   ○ Yes
   ○ No
3. The number of official employees in your enterprise is approximately: [Single choice]
   ○ Under 50
   ○ 50–100
   ○ 101–150
   ○ 151–200
   ○ More than 200
4. At present, the main way of generating electricity in your enterprise is _____ (Choose at most 2 items) [Multiple choice]
   ☐ Thermal power generation
   ☐ Hydroelectric power generation
   ☐ Wind power generation
   ☐ Photovoltaic power generation
   ☐ Biological power generation
   ☐ Geothermal power generation
   ☐ Tidal power
   ☐ Other green electricity
5. Annual comprehensive average energy consumption range of your enterprise in the last three years (unit: tons of standard coal/year) [Single choice]
   ○ <5000
   ○ 5000–10,000
   ○ >=10,000
6. Which of the following is most closely related to your enterprise's carbon emission status? [Single choice]
   ○ Almost achieved carbon neutrality within the company.
   ○ Already peaked, but not yet achieved carbon neutrality within the company, and continuing to reduce emissions.
   ○ Not yet peaked, and is expected to peak by 2025.
   ○ Not yet peaked, and is expected to peak by 2030.
   ○ Not yet peaked, uncertain about the time to reach carbon peak.
7. Has your enterprise participated in carbon emission rights trading in 2021? [Single choice]
   ○ Yes
   ○ No

   II. Attitude and goal
8. How does your enterprise view the impact of "carbon peak and carbon neutrality" on your company? [Single choice]
   ○ Under pressure
   ○ Beneficial

○ Have little effect on
○ Have not paid attention to

9. Your enterprise thinks that "carbon peak and carbon neutrality" puts pressure on the company, mainly because the dual-carbon target makes the company _____ (Choose at most 3 items) [Multiple choice]
☐ Limited scale of development
☐ Faced with increasingly stringent emission reduction policies
☐ Facing more fierce market competition
☐ Power generation costs are rising and profit expectations are falling
☐ The economic and human costs of carbon management increase
☐ Others (please add)
10. Your enterprise believes that "Carbon peak · Carbon neutrality" is beneficial to the company, mainly because the two-carbon target enables the company _____. (Choose at most 3 items) [Multiple choice]
☐ Have more development opportunities
☐ The emission reduction work has received strong policy support
☐ The market demand in the industry is increasing
☐ Market competitiveness has increased, and profit expectations have risen
☐ We will accelerate industrial transformation and upgrading
☐ Others (please add)
11. Whether your enterprise low-carbon development goals have been determined? [Single choice]
○ Yes, short-term emission reduction targets have been set for the next three years
○ Yes, short- and medium-term emission reduction targets have been set for the next five years
○ Yes, medium- and long-term emission reduction targets have been set for the next 10 years
○ Yes, long-term emission reduction targets have been set for the next 30 years and beyond
○ No, it is under consideration, but not yet determined
○ No, haven't considered
12. If given the opportunity, would your company be willing to participate in carbon trading? [Single choice]
○ Willing to attend
○ Don't want to attend
○ I don't know. I'm not sure

III. Regime and management system

13. Whether your enterprise has a dedicated carbon asset management organization/department? [Single choice]
○ Has been set
○ Hasn't set any plans at present
○ No, but we has cooperated with a third party
14. The number of full-time carbon asset management personnel in your enterprise accounts for about all the employees of the enterprise [Single choice]
○ 1% and below
○ 1–5% (including 5%)
○ 5–10% (including 10%)
○ 10–15% (including 15%)
○ 15–20% (including 20%)
○ More than 20%
15. In which of the following tasks does your enterprise have a clear management system document? (Choose at most 3 items) [Multiple choice]
☐ Carbon inventory
☐ Carbon trading

☐ Carbon reduction
☐ Carbon finance
☐ The above work has a clear management system documents
☐ None

16. How is your enterprise prepared to participate in the carbon emission trading system in the following aspects? [Matrix Single choice]

	Has Been Carried Out	In Preparation, Plan to Carry Out	There Is No Plan
Carbon inventory work	○	○	○
Carbon trading market status, and policy research	○	○	○
Carbon reduction potential and cost analysis	○	○	○
CCER development and trading	○	○	○
Carbon management personnel training	○	○	○
Innovation and application of carbon financial instruments	○	○	○

17. Please rank the following options from strong to weak in terms of the likelihood that your enterprise will trade carbon in the future. [Ranking question] (Please fill in 1–4 numeric order)
_____ Carbon emission rights and CCER spot trading
_____ carbon asset mortgage financing
_____ Buy financial futures products
_____ Trusteeship of carbon assets to specialist companies and agreement of income
IV. Running process
18. The main ways for your enterprise to obtain carbon trading information are (Choose at most 3 items) [Multiple choice]
☐ Government propaganda
☐ News media (including traditional media such as TV programs, newspapers and new media such as public accounts and short videos)
☐ Industry/trading website
☐ Training institution
☐ Haven't looked at the carbon market
☐ Others (please specify)
19. In what ways does your company plan to achieve carbon reduction? (Choose at most 3 items) [Multiple choice]
☐ Save energy and reduce consumption (improve energy efficiency)
☐ New energy substitution (Such as coal to gas, coal to electricity, the use of hydrogen energy, wind energy, photovoltaic and other new energy)
☐ Update equipment and technology
☐ Establish a sustainable energy management system
☐ Purchase carbon management consulting services (to be managed by a third party)
☐ There is no carbon reduction plan
☐ Others (please specify)
20. If takes measures to reduce emissions, how much of your annual revenue do you plan to spend on this action each year? (Please fill in 1–100 numbers) [Marking question] Please slide according to the proportion, if no budget please slide to "0" _____
21. Has your company ever designed and developed CCER projects or considered developing them? [Single choice]
○ Designed and developed, has been registered successfully and produces emission reduction

○ Considering development, waiting for more clear policy (or project design planning)
○ No, hasn't considered

22. Does your company have financing needs in addition to its own funds for low-carbon transformation [Single choice]
○ Yes, the financing capital requirement is about ____ yuan
○ No

V. Effect

23. In terms of the following work in carbon asset management, how is your company's completion status in 2021? [Matrix Single choice]

	Worked very Well, It Finished the Plan with High Quality	**The Effect Is General, Can Complete the Plan but More Difficult**	**Unable to Achieve Expectations, Needs Help**	**There Is No Plan**
Carbon inventory work	○	○	○	○
Power generation work(Production business)	○	○	○	○
Carbon trading work(If you do not participate, please select "No plan")	○	○	○	○
Carbon reduction efforts	○	○	○	○
CCER project development	○	○	○	○
Carbon management personnel training	○	○	○	○

24. According to the actual effect of your company's current management and emission reduction, does your company expect to join carbon emission trading in the future? (The Measures for the Administration of Carbon Emission Trading (Trial) stipulate that enterprises with annual energy consumption of more than 1000 tons of standard coal or annual carbon emissions of more than 26,000 tons of equivalent are key emission units) [Single choice]
○ Have joined or will join this year
○ In the short term (within the next three years) may join
○ In the long term (after the next three years or more) may join
○ Will not join in the future

25. What are the main difficulties your company encountered by enterprises in achieving emission reduction plans in 2021 (if there is no plan, what difficulties do you think you may encounter if you carry out emission reduction work?) (Choose at most 3 items) [Multiple choice]
☐ Increasing emission reduction costs
☐ Technology updates are slow
☐ The internal decision-making system is not perfect
☐ Its potential to reduce emissions is not clear
☐ Estimating the cost of carbon reduction is difficult
☐ Others (please specify)

26. What problems or difficulties do you think exist in the current financial support for low-carbon projects (Choose at most 3 items) [Multiple choice]
☐ Financial institutions lack the awareness to support green and low-carbon
☐ Financial institutions have shown little support for green projects
☐ Information asymmetry between banks and enterprises
☐ The relevant financial markets (such as mortgage, factoring, etc.) are not well developed
☐ Lack of professional technical consulting services
☐ Others (please specify)

27. Based on the effectiveness of your carbon management, which of the following services does your company require from a third party organization/company? (Multiple options available) [Multiple choice]
☐ Guidance on formulating low-carbon development strategies and plans for enterprises
☐ Carbon emissions accounting Agency and Guidance Report
☐ Carbon reduction potential analysis and carbon reduction work
☐ Carbon asset management and trading personnel training
☐ No third party services are required
☐ Others (please specify)
28. Based on the effectiveness of your carbon asset management, what other help does your company need? What are the suggestions for China to achieve "carbon peak, carbon neutrality"? (For example, which incentives for the research and development of clean energy power generation technologies can be given by the state, and which aspects require the cooperation of other industries, etc.) Please give at least one [Fill in the blanks]

_____

Appendix B.

Table A1. Impact of different factors on the preparedness of power generation companies for carbon asset management (one-way ANOVA results).

Indicator	Factor	Level	N	Average Value	Standard Deviation	F	Sig	Multiple Comparisons
CCER development and trading	Carbon emission status	1. Almost achieved carbon neutrality within the company.	6	1.17	0.41	5.232	0.001	1 < 5, 2 < 5, 3 < 5
		2. Already peaked, but not yet achieved carbon neutrality within the company, and continuing to reduce emissions.	13	1.15	0.38			
		3. Not yet peaked, and is expected to peak by 2025.	19	1.32	0.58			
		4. Not yet peaked, and is expected to peak by 2030.	25	1.64	0.86			
		5. Not yet peaked, uncertain about the time to reach carbon peak.	87	1.84	0.70			
	Comprehensive average energy consumption range in the past three years (ton of standard coal/year)	1. <5000	65	1.97	0.68	17.579	0	3 < 2 < 1
		2. 5000–10,000	68	1.51	0.70			
		3. >=10,000	17	1.00	0.00			
	Whether the enterprise low-carbon development goals have been determined	1. Yes, short-term emission reduction targets have been set for the next 3 years.	24	1.67	0.70	2.883	0.016	1 < 6, 2 < 3, 2 < 6, 4 < 6
		2. Yes, short-and medium-term emission reduction targets have been set for the next five years.	41	1.39	0.63			
		3. Yes, medium-and long-term emission reduction targets have been set for the next 10 years.	41	1.80	0.75			
		4. Yes, long-term emission reduction targets have been set for the next 30 years and beyond.	9	1.44	0.73			
		5. No, it is under consideration, but not yet determined.	29	1.72	0.75			
		6. No, haven't considered.	6	2.33	0.52			

Table A1. *Cont.*

Indicator	Factor	Level	N	Average Value	Standard Deviation	F	Sig	Multiple Comparisons
	Whether the enterprise has a dedicated carbon asset management organization/department	1. Has been set	56	1.23	0.54	19.096	0	1 < 2, 1 < 3
		2. Has nott set any plans at present	45	1.96	0.64			
		3. No, but we have cooperated with a third party.	49	1.86	0.76			
Carbon trading market status, and policy research	Comprehensive average energy consumption range in the past three years (ton of standard coal/year)	1. <5000	65	1.43	0.61	4.96	0.008	3 < 2
		2. 5000–10,000	68	1.69	0.68			
		3. >=10,000	17	1.24	0.44			
	Whether the enterprise has a dedicated carbon asset management organization/department	1. Has been set.	56	1.36	0.52	8.273	0	1 < 3, 2 < 3
		2. Has not set any plans at present.	45	1.42	0.69			
		3. No, but we has cooperated with a third party.	49	1.82	0.64			
Carbon reduction potential and cost analysis	Whether the enterprise has a dedicated carbon asset management organization/department	1. Has been set	56	1.46	0.57	3.095	0.048	1 < 2, 1 < 3
		2. Has not set any plans at present.	45	1.73	0.75			
		3. No, but we have cooperated with a third party.	49	1.76	0.69			

Table A2. Impact of different factors on the completion of carbon asset management work in power generation companies in 2021 (one-way ANOVA results).

Indicator	Factor	Level	N	Average Value	Standard Deviation	F	Sig	Multiple Comparisons
Carbon trading	Whether the enterprise has a dedicated carbon asset management organization/department	1. Has been set.	56	2.21	1.04	30.877	0	1 < 2, 1 < 3
		2. Has not set any plans at present.	45	3.58	0.87			
		3. No, but we have cooperated with a third party.	49	3.37	0.93			
Power generation	Whether the enterprise low-carbon development goals have been determined	1. Yes, short-term emission reduction targets have been set for the next 3 years.	24	1.46	0.51	4.756	0	1 < 3, 2 < 3, 2 < 6, 3 > 4, 3 > 5
		2. Yes, short- and medium-term emission reduction targets have been set for the next 5 years.	41	1.37	0.58			
		3. Yes, medium- and long-term emission reduction targets have been set for the next 10 years.	41	2.05	0.89			
		4. Yes, long-term emission reduction targets have been set for the next 30 years and beyond.	9	1.44	0.73			
		5. No, it is under consideration, but not yet determined.	29	1.69	0.71			
		6. No, have not considered.	6	2.00	0.63			

Table A2. *Cont.*

Indicator	Factor	Level	N	Average Value	Standard Deviation	F	Sig	Multiple Comparisons
Carbon emission reduction	Whether the enterprise low-carbon development goals have been determined	1. Yes, short-term emission reduction targets have been set for the next 3 years.	24	1.63	0.82	2.522	0.032	1 < 3, 1 < 5, 1 < 6, 2 < 3, 2 < 6
		2. Yes, short- and medium-term emission reduction targets have been set for the next 5 years.	41	1.83	0.77			
		3. Yes, medium- and long-term emission reduction targets have been set for the next 10 years.	41	2.22	0.85			
		4. Yes, long-term emission reduction targets have been set for the next 30 years and beyond.	9	1.78	0.83			
		5. No, it is under consideration, but not yet determined.	29	2.14	0.92			
		6. No, have not considered.	6	2.5	1.05			
	Whether the enterprise has a dedicated carbon asset management organization/department	1. Has been set.	56	1.66	0.67	8.088	0	1 < 2, 1 < 3
		2. Has not set any plans at present.	45	2.04	0.85			
		3. No, but we have cooperated with a third party.	49	2.31	0.96			
Carbon inventory	Whether the enterprise has a dedicated carbon asset management organization/department	1. Has been set.	56	2.45	1.40	3.497	0.033	1 < 3
		2. Has not set any plans at present.	45	2.87	1.38			
		3. No, but we have cooperated with a third party.	49	3.12	1.18			

References

1. National Development and Reform Commission. Notice on Carbon Emission Trading Pilot Work (NDRC QI [2011] 2601). Available online: https://zfxxgk.ndrc.gov.cn/web/iteminfo.jsp?id=1349 (accessed on 27 July 2024).
2. Ministry of Ecology and Environment of the People's Republic of China. Measures for the Administration of Carbon Emission Trading (for Trial Implementation). Available online: https://www.gov.cn/zhengce/2021-01/05/content_5711435.htm (accessed on 27 July 2024).
3. Marland, G.; Sedijo, R.; Fruit, K. Accounting for sequestered carbon: The question of permanence. *Environ. Sci. Policy* **2001**, *4*, 259–268. [CrossRef]
4. Julien, C. Carbon futures and macroeconomic risk factors: A view from the EUETS. *Energy Econ.* **2009**, *31*, 614–625.
5. Tao, C.H. Carbon assets: A new concept of eco-environmental protection--research on concept, significance and implementation path. *Acad. Forum* **2016**, *39*, 64–67.
6. Zhao, Y.F.; Li, J.J.; Zhang, J. Recognition and Measurement of Carbon Assets Based on Carbon Emission Right Attributes. *Financ. Theory Pract.* **2018**, *466*, 1–4.
7. Yuan, G.D.; Xu, D.Y. Carbon accounting research on the convergence of dual-carbon objectives. *Friends Account.* **2023**, *698*, 101–107.
8. Wang, C.; Liao, L.G.; Li, X.W. Can environmental protection and banking development be synergized?—An analysis based on the low-carbon city pilot in China. *Environ. Sci. Pollut. Res.* **2022**, *31*, 10016–10031.
9. Wang, H.; Yang, H.; Liu, D. Research on the Countermeasures for Power Generation Enterprises under the Impact of Carbon Emission Trading System. *IOP Conf. Ser. Earth Environ.Sci.* **2019**, *237*, 062017. [CrossRef]
10. Xu, X.; Guan, C.; Jin, J. Valuing the carbon assets of distributed photovoltaic generation in China. *Energy Policy* **2018**, *121*, 374–382. [CrossRef]
11. Liu, Y.; Tian, L.; Xie, Z.; Sun, H. Option to survive or surrender: Carbon asset management and optimization in thermal power enterprises from China. *J. Clean. Prod.* **2021**, *314*, 128006. [CrossRef]
12. Burritt, R.L.; Schaltegger, S.; Zvezdov, D. Carbon management accounting: Explaining practice in leading German companies. *Aust. Acc. Rev.* **2011**, *21*, 80–98. [CrossRef]
13. Zhang, C.P.; Randhir, T.O.; Zhang, Y. Theory and practice of enterprise carbon asset management from the perspective of low-carbon transformation. *Carbon Manag.* **2018**, *9*, 87–94. [CrossRef]
14. Shen, Y.; Su, Z.-W.; Huang, G.; Khalid, F.; Farooq, M.B.; Akram, R. Firm market value relevance of carbon reduction targets, external carbon assurance and carbon communication. *Carbon Manag.* **2020**, *11*, 549–563. [CrossRef]

15. Naranjo Tuesta, Y.; Crespo Soler, C.; Ripoll Feliu, V. The Influence of Carbon Management on the Financial Performance of European Companies. *Sustainability* **2022**, *12*, 4951. [CrossRef]
16. Nishitani, K.; Kokubu, K. Why does the reduction of greenhouse gas emissions enhance firm value? The case of Japanese manufacturing firms. *Bus. Strateg. Environ.* **2012**, *21*, 517–529. [CrossRef]
17. Zhen, G. Carbon asset management of key emitting enterprises under the national carbon market. *Mod. Commer. Trade* **2021**, *42*, 87–88.
18. Yang, G.J.; Xu, Z.; Shen, F.H. Current situation analysis and prospect of carbon emissions reduction and participation in carbon trading market in the power generation industry. *Environ. Prot.* **2018**, *46*, 22–26.
19. Li, Y.S.; Cai, T.L.; Wang, L.; Zhao, S.; Zhang, L. A review of research on the planning and construction of carbon asset management system. *Electr. Power Electr. Eng.* **2023**, *11*, 14–18.
20. Hrasky, S. Carbon footprints and legitimation strategies: Symbolism or action? *Account. Audit. Account. J.* **2012**, *25*, 174–198. [CrossRef]
21. Liu, Z.; Zhang, C. Quality evaluation of carbon information disclosure of public companies in China's electric power sector based on ANP-Cloud model. *Environ. Impact Assess. Rev.* **2022**, *96*, 106818. [CrossRef]
22. Chen, N. Construction and Application of Carbon Asset Management System for H Power Enterprises Based on Enterprise Value Creation. Master's Thesis, Lanzhou University of Technology, Lanzhou, China, 2023.
23. Jiang, Y.; Hu, Y.; Asante, D.; Ampaw, E.M.; Asante, B. The Effects of Executives' low-carbon cognition on corporate low-carbon performance: A study of managerial discretion in China. *J. Clean. Prod.* **2022**, *357*, 132015. [CrossRef]
24. Hu, X.Y.; Cao, W.W.; Qin, Z. Research on the current situation of domestic carbon emission trading market. *China Explor. Des.* **2023**, *S1*, 64–68.
25. Song, H.Y.; Zhang, X.X.; Zhang, G. The Development and Problems of China's Carbon Market. *IOP Conf. Ser. Earth Environ. Sci.* **2020**, *440*, 042100. [CrossRef]
26. Wang, P. Research on Multi-Market Coupled Trading Model for Wind and Solar Energy Generation Companies. Ph.D. Thesis, North China Electric Power University, Beijing, China, 2023.
27. Tao, C.H. Research on Enterprise Carbon Asset Management Oriented to Value Creation. Ph.D. Thesis, Beijing Jiaotong University, Beijing, China, 2016.
28. Yu, C.X. Research on Carbon Trading Model of Multi-Energy Coupled System in Carbon Financial Market. Master's Thesis, Kunming University of Science and Technology, Kunming, China, 2023.
29. Wang, L.P.; Long, Y.; Li, C. Research on the impact mechanism of heterogeneous environmental regulation on enterprise green technology innovation. *J. Environ. Manag.* **2022**, *322*, 116127. [CrossRef] [PubMed]
30. Pricewaterhouse Coopers. [State-Owned Enterprise Reform Observatory] Thoughts on the Management of Carbon Emissions in State-Owned Enterprises. Available online: https://mp.weixin.qq.com/s/UQ-ImQaoU_3gu1tjBocaQA (accessed on 10 May 2023).
31. Xinxiangxin. Current Situation and Breakthrough of Carbon Asset Management in China. Available online: https://mp.weixin.qq.com/s/ygcguD-sd4dOJRph6nfbLA (accessed on 10 February 2022).
32. Ministry of Ecology and Environment. Notice on the Issuance of the "Implementation Plan for the Total Quota Setting and Allocation of National Carbon Emission Trading in 2019–2020 (Power Generation Industry)" and the "List of Key Emission Units included in the Management of National Carbon Emission Trading Quotas in 2019–2020" and the Pre-Allocation of Quotas for the Power Generation Industry (Guohuan Climate [2020] No. 3). Available online: https://www.mee.gov.cn/xxgk2018/xxgk/xxgk03/202012/t20201230_815546.html (accessed on 10 February 2022).
33. Liu, Y.; Xu, L.; Sun, H.; Chen, B.; Wang, L. Optimization of carbon performance evaluation and its application to strategy decision for investment of green technology innovation. *J. Environ. Manag.* **2023**, *325 Pt A*, 116593. [CrossRef]
34. Ma, M. The first compliance period "ends", and the national carbon market starts a new journey. *Financial Times*, 6 January 2022.
35. Zhang, T.; Zou, S.H. Carbon Market Evaluation Based on Random Walk Hypothesis in China. *Math. Probl. Eng.* **2022**, *2022*, 726108. [CrossRef]
36. Hou, B.J. Current situation analysis and countermeasures for energy-saving and environmental protection enterprises participating in the carbon market. *Resour. Conserv. Environ. Prot.* **2020**, *8*, 141.
37. Liu, Z. Research on Carbon Inventory Methods and Index System in the Power Industry. Master's Thesis, North China Electric Power University, Beijing, China, 2013.
38. Li, R.; Zhang, Y.Q.; Liu, C.Q.; Tang, X.M. Ideas and suggestions for large power groups to build a carbon management system. *Mod. State-Own. Enterp. Res.* **2017**, *24*, 220–221.
39. Cao, Y.; Zha, D.L.; Wang, Q.W.; Wen, L. Probabilistic carbon price prediction with quantile temporal convolutional network considering uncertain factors. *J. Environ. Manag.* **2023**, *342*, 118137. [CrossRef]
40. Liu, Y.; Tian, L.; Sun, H.; Yuan, L.; Zhang, X. Marginal return-ability measurement of carbon emission right and its application to unification route analysis of carbon markets. *Clean. Prod.* **2022**, *345*, 130684. [CrossRef]
41. Liu, J.; Zhang, C. A Neural Network Model for Digitizing Enterprise Carbon Assets Based on Multimodal Knowledge Mapping. *Comput. Intell. Neurosci.* **2022**, *2022*, 4485168. [CrossRef]
42. Shang, N.; Chen, Z.; Lu, Z.L.; Leng, Y. Interaction mechanism and coordination mechanism of power market, carbon market and green certificate market. *Power Syst. Technol.* **2022**, *9*, 1–13.

43. Zhang, Y.X.; Zhao, X.H.; Fu, B.W. Impact of energy saving on the financial performance of industrial enterprises in China: An empirical analysis based on propensity score matching. *J. Environ. Manag.* **2022**, *317*, 115377. [CrossRef] [PubMed]
44. Meng, Z.M.; Ge, X.A. *Practical Operation of Carbon Emission Trading in China*; Chemical Industry Press: Beijing, China, 2016; Volume 270, p. 292.
45. Ding, L.L. Research on Enterprise Carbon Emission Reduction Decision-Making Based on Multi-Level Equilibrium. Master's thesis, Jiangsu University, Zhenjiang, China, 2020.
46. Chen, J.; Li, H.P.; Lin, J.H.; Li, S.Y. Research on low-carbon transformation problems and paths of China's power industry under the carbon neutrality target. In Proceedings of the 2021 Annual Conference of the Chinese Society for Environmental Sciences, Tianjin, China, 19–21 October 2021.
47. Peng, Y.H. Analysis of the Decoupling Effect of Carbon Emissions and Economic Growth in China's Power Industry. Master's Thesis, North China University of Water Resources and Electric Power, Zhengzhou, China, 2021.
48. Lu, Y.G. Study on carbon efficiency and carbon emission reduction cost of China's thermal power enterprises. Master's Thesis, Zhejiang University, Hangzhou, China, 2019.
49. Wolf-Peter, S.; Alexander, Z. Long-run power storage requirements for high shares of renewables: Results and sensitivities. *Renew. Sustain. Energy Rev.* **2018**, *83*, 156–171.
50. Wang, K.; Li, S. China's Carbon Market: Reviews and Prospects (2022). *J. Beijing Univ. Technol. (Soc. Sci. Ed.)* **2022**, *24*, 33–42.
51. Xia, M.Y.; Chuai, X.W.; Xu, H.B.; Cai, H.H.; Xiang, A.; Lu, J.; Li, M. Carbon deficit checks in high resolution and compensation under regional inequity. *J. Environ. Manag.* **2023**, *328*, 116986. [CrossRef] [PubMed]
52. Sun, Q.F.; Nian, Z.Q. Practice and system construction of green finance under the "dual carbon" vision. *J. Fujian Norm. Univ. (Philos. Soc. Sci. Ed.)* **2022**, *1*, 71–79.
53. Ma, Y.R.; Chen, B. On the current development and operation mechanism of China's carbon funds. *Acad. Exch.* **2011**, *10*, 131–135.
54. Chen, Y.F. Enterprise Competition and Cooperation in Supply Chain Carbon Finance. Master's Thesis, South China University of Technology, Guangzhou, China, 2017.
55. Shi, B.B.; Li, N.; Gao, Q.; Li, G.Q. Market incentives, carbon quota allocation and carbon emission reduction: Evidence from China's carbon trading pilot policy. *J. Environ. Manag.* **2022**, *319*, 115650. [CrossRef]
56. Zou, S.; Zhang, T. Correlation and dynamic volatility spillover between green investing market, coal market, and CO_2 emissions: Evidence from Shenzhen carbon market in China. *Adv. Civ. Eng.* **2022**, *2022*, 7523563. [CrossRef]

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