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The Evaluation of Enterprise Carbon Trading Audit Based on DSR Model and GHG Accounting

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Abstract

INTRODUCTION: With the continuous development of social economy, environmental issues are becoming increasingly apparent. How to maintain the coordination of environmental and economic development is an urgent issue to be addressed. This study takes carbon trading as an example, starting with enterprise CAE, proposes a CAE index system that combines DSR model and GHG accounting, and hopes to urge enterprises to reduce carbon emissions during development.
OBJECTIVES: Carbon audit is an important way to evaluate the low carbon development of enterprises. To effectively realize the evaluation of enterprise carbon audit, the study takes cement enterprises for instance and proposes a carbon audit evaluation (CAE) standard.
METHODS: Firstly, it adopts the greenhouse gas (GHG) accounting method to monitor the carbon release of cement companies, and secondly, the main factors are analyzed based on the data obtained from the monitoring, and then the driving-force state-response (DSR) index system is constructed to realize the evaluation of carbon trading audit of cement enterprises.
RESULTS: The results show that the accuracy of the adopted carbon emission monitoring method is 99.3%, which is significantly higher than the other methods, and the error is only 0.1 after stabilization. Finally, after the CAE, we can see that the CAE method proposed by the study is reasonable and feasible with the actual situation with a fit of 0.954, which means that the evaluation method proposed by the study is reasonably practicable.
CONCLUSION: It is necessary to combine the DSR model with the GHG accounting approach to conduct the enterprise CAE, which can improve the enterprise CAE system and is of great value to the improvement of the efficiency of the enterprise CAE.

Keywords: Carbon audit, GHG accounting, DSR, Carbon emission monitoring.

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1. Introduction

With the rapid development of the global economy and the increasing complexity of human society, the issue of carbon emissions generated by enterprises in the production and operation process has attracted widespread attention. Greenhouse gas emissions not only have a serious impact on climate change, but also affect the sustainable development and social responsibility of enterprises [1]. In order to cope with the challenge of climate change, the international community has gradually introduced a carbon trading system to encourage companies to adopt low-carbon development paths and promote greenhouse gas emission reductions. In this context, corporate carbon trading audit evaluation has become one of the hot topics of research. However, traditional corporate carbon trading audit evaluation research mainly relies on traditional greenhouse gas accounting methods and assessment models. These methods often ignore the dynamics and uncertainty of carbon trading, and are difficult to fully and accurately reflect the actual status of corporate carbon trading [2]. The shortcomings of traditional research include but are not limited to static audits of corporate carbon emission data and lack of real-time monitoring and response mechanisms to dynamic changes; greenhouse gas accounting methods are too simplified and

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difficult to comprehensively assess corporate carbon footprints; corporate carbon trading risks the evaluation is relatively simple and lacks global and systematic analysis [3-4]. Therefore, this study uses the DSR (Dynamic Systems Research) model as the theoretical framework and combines greenhouse gas accounting technology to conduct audit and evaluation research on corporate carbon trading. The DSR model can better capture the dynamic characteristics of corporate carbon trading and achieve an in-depth understanding of the carbon trading process through real-time monitoring and dynamic analysis of corporate carbon emission data. At the same time, greenhouse gas accounting technology is introduced to conduct refined calculations of corporate carbon emissions, improving the accuracy and operability of audit evaluations. Research innovations are mainly reflected in the overall and systematic risk assessment of carbon trading, which provides an important reference for enterprises to formulate more scientific and reasonable carbon trading strategies. The research is expected to improve the management level of enterprises in the field of carbon trading, promote enterprises to better fulfill their social responsibilities, and promote the realization of sustainable development.

The research has four contributions. First, by introducing advanced greenhouse gas accounting technology, the research established a comprehensive and accurate corporate carbon emission monitoring indicator system, making corporate carbon trading audits more operable and practical. Second, combined with the DSR model, a dynamic and systematic corporate carbon trading audit evaluation index system was constructed, making the evaluation of corporate carbon trading processes more timely and global, and improving the scientificity and accuracy of the evaluation indicators. Third, through experimental analysis, the study evaluated the effect of corporate carbon emission monitoring based on greenhouse gas accounting, verified the reliability and accuracy of the monitoring indicator system, and provided scientific carbon emission data support for enterprises. Fourth, under the guidance of the DSR model, the enterprise carbon trading process was evaluated through experiments, and the changing trends of various indicators in a dynamic environment were deeply analyzed, providing enterprises with a more comprehensive carbon trading risk assessment and laying the foundation for formulating reasonable carbon trading policies. Trading strategies provide strong support.

The research is divided into four parts. The first part is a summary of the existing research content. The second part is the construction of the enterprise carbon trading audit evaluation index system. The third part is the experimental analysis of the enterprise carbon trading audit evaluation. The fourth part is the full text. summary.

2. Related works

The green transformation of economy and energy saving and emission reduction of industry is a comprehensive development problem faced by all countries in the world, and carbon audit is of great value to promote CER. The CAE is achieved from four perspectives, and the efficacy coefficient method is used for standardization to obtain standardized scores for different indicators [5]. The scholars in [6] proposed a carbon trading evaluation strategy using wavelet transform and deep learning techniques to solve the issue of carbon trading for energy saving and emission reduction in China, using wavelet transform for image processing and data analysis, extracting image edges to obtain carbon emission trading price fluctuations and other data, and then combined with deep learning algorithm to extract feature points in carbon trading data to achieve carbon trading value assessment . The scholars in [7] explored the relationship between carbon emission information disclosure and the long- and short-term performance based on listed companies in the high pollution development field from 2009-2019, and analyzed the influence role of carbon emission information disclosure of listed companies from equity structure, and the study. The results indicate that information disclosure has a good effect on the long-term enterprise value growth of listed companies. The scholars in [8] proposed a carbon emission costing method for corporate energy supply and CER issues, which accounts for carbon emission costs from internal and external perspectives and combines an extended calculation model to measure the life cycle of corporate products, providing an information basis for management decisions and CER governance. The scholars in [9] conducted carbon management audits of four major carbon emitting industries in Australia, such as electricity and agriculture, by means of questionnaires and data collection, and conducted survey interviews with senior managers of companies in high-emission industries in Australia to obtain information about companies in CER and sustainable development, and to explore the role of carbon management audits in corporate development. The scholars in [10] collected panel data of 31 provincial-level administrative regions in China from 2011 to 2019, involving ecological environment and digital economy. Through the threshold effect test, it was found that there are two thresholds in the model, and threshold regression analysis was performed to reveal the trend of the impact of the digital economy on the ecological environment. It is recommended that policymakers further promote the development of the digital economy, encourage the optimization of regional industrial structures, and increase technological investment support to ensure the coordination of environment and economic development in the digital economy era.

Sustainable development is the future direction of social and industrial development, and many researchers have introduced various assessment and analysis models for sustainable development assessment. -Impact-Response (DPSIR) model to analyze the relationship between nature tourism development and regional sustainability, and to propose sustainability goals for special tourism development areas in the context of social feedback. The findings suggest that multi-layer management and monitoring should be strengthened to promote sustainable tourism development based on a strong institutional development capacity. The scholars in [11] used data envelopment analysis (DEA) to identify the efficiency of PTR and DSR farms and to determine energy optimization. A comparison is made between PTR (92.4%) and DSR (60.3%) methods by evaluating the use of non-renewable energy inputs. DEA was used to determine the efficiency of 26 PTR farms and 87 DSR farms. The findings show that adopting a DSR approach is critical to reducing energy consumption and GHG emissions to achieve carbon sustainability. The scholars in [12] combined the DPSIR model to assess China's water poverty in 1997-2014, analyze China's water scarcity from the perspective of resource management, and use the least squares method to determine the spatial pattern of water distribution. Promote water resources environmental management at both spatial and temporal levels. The scholars in [13] members address the air pollution problem in Henan Province, analyze and assess the changes in air quality levels in Henan from 2013-2017 from a number of air quality assessment indicators, and explore the influencing factors of air quality changes by combining data on economic growth and urban development to achieve Henan air pollution Comprehensive risk assessment. The scholars in [14] built a carbon audit evaluation index system based on carbon audit theory and DSR model, analyzed the application of the evaluation index system, and evaluated its role in implementing carbon audits, improving corporate carbon audit systems and evaluation mechanisms, and optimizing corporate energy conservation and emission reduction processes. and its positive contribution to the low-carbon economy. The scholars in [15] proposed a sustainability assessment model for shale gas resources by combining the driving force analysis model and improved genetic algorithm, determined the relevant index system for sustainable utilization of shale gas through the comprehensive analysis of driving force, pressure and other factors, and made a comprehensive assessment of shale gas utilization by combining actual energy utilization data. The scholars in [16] combined remote sensing image analysis and statistical analysis of data to conduct a comprehensive assessment of the spatial distribution of ecological environment in Sichuan Province, and use a geographically weighted regression model to explore the spatial impact of urban expansion and human activities on ecological environment, providing an evaluative data reference for regional ecological decision-making.

To sum up, many experts have conducted research on issues such as economic green transformation and industrial energy conservation and emission reduction, carbon trading, carbon emission information disclosure, corporate energy supply and carbon emission reduction, but there are still some insufficient infrastructure and carbon trading issues. Problems such as shortage of carbon audit talents. Therefore, this study proposes a study on corporate carbon trading audit evaluation based on DSR model and greenhouse gas accounting to solve the carbon trading problem, improve the effect of carbon emission information disclosure, and optimize corporate energy supply and carbon emission reduction management. In contrast, the research method is innovative and comprehensive and can help companies make more targeted decisions in low-carbon economy and sustainable development.

3. Enterprise carbon trading audit evaluation index system construction

3.1. Enterprise carbon emission monitoring based on GHG accounting

As a basic industry in China, the cement industry accounts for a relatively high share of carbon emissions in total industrial emissions, and is the second highest emitting industry after the power industry. Strengthening the carbon trading audit of cement enterprises is the basis for promoting the double carbon action. The study realizes the carbon emission monitoring of cement enterprises through GHG accounting. Based on the process characteristics of production and emission of cement enterprises, the emission factor method is used to account for and monitor the carbon emission [17-18]. The production of cement enterprises is shown in Figure 1. It is mainly divided into two parts: clinker production and finished product production. The output of commercial cement requires mixing clinker obtained from pre-production with certain amount of gypsum and other ingredients, and using specific processing process materials to complete the operations of material mixing and grinding to make the final finished cement.

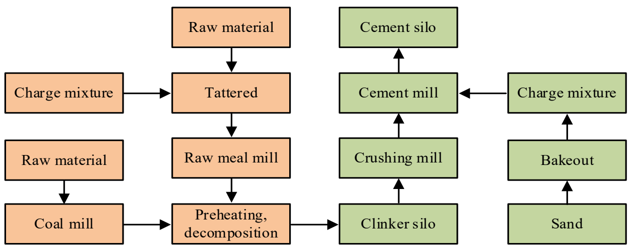

Figure 1. Production process of cement enterprises

As shown in Figure 1, the first stage of the production process is the production of clinker. At this stage, raw materials include limestone (high calcium content), clay (containing silicon, iron, aluminum and other elements) and other auxiliary raw materials, such as iron ore and bauxite, etc., which are put into the clinker kiln in precise proportions. The clinker kiln is a large rotating cylindrical equipment that chemically reacts with raw materials to form clinker through high-temperature calcination. Greenhouse gases such as carbon dioxide are released during this process. After clinker production is completed, the clinker needs to be further processed and mixed with appropriate amounts of ingredients such as gypsum to adjust the hardening time and properties of the cement. This mixing process usually occurs in a cement mill, where the raw materials are mixed evenly through grinding and stirring. The mixture is then packaged into the final finished cement through a cement packaging machine. At this stage, a certain amount of greenhouse gases will also be produced, mainly due to energy consumption and the processing of raw materials. In addition to clinker and finished product production, the production process of cement companies may also involve some auxiliary processes, such as energy supply, transportation, waste treatment, etc. [19]. These processes may also have an impact on greenhouse gas emissions and need to be considered in overall greenhouse gas accounting. In the calculation of carbon dioxide emissions, we first analyze the carbon emission accounting boundaries of cement companies to determine the calculation direction, see Figure 2.

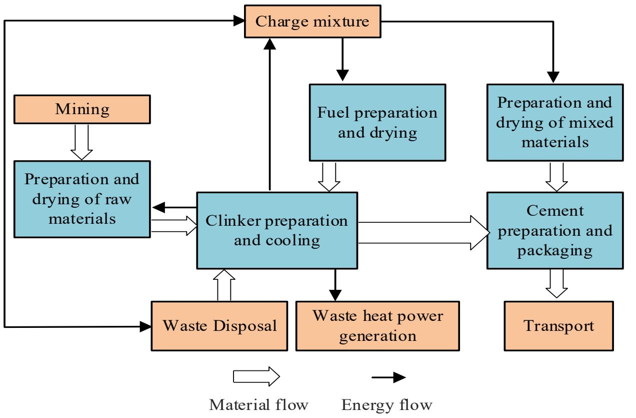

Figure 2. Carbon emission accounting boundary of cement enterprises

The greenhouse gas emission accounting boundaries of cement companies involve three main types, namely auxiliary production systems, direct production systems and ancillary production systems. First, ancillary production systems include the company's indirect emissions, mainly from purchased electricity and heat. Within this scope, cement companies need to account for greenhouse gas emissions generated from energy purchased from outside. Secondly, the direct production system includes greenhouse gas emissions generated during the company's own production process. This includes the extraction of raw materials, fuel combustion, clinker production, clinker burning, and cement grinding and packaging. Emissions within this boundary are directly controlled and managed by the company. Finally, ancillary production systems cover other indirect emissions related to the company's value chain, such as the production and transportation of raw materials, transportation of products, waste disposal, etc. These emissions are usually not directly controlled by companies, but companies can take steps to reduce their indirect impacts. Let the carbon dioxide emissions due to fuel combustion in the enterprise be E_b, and the carbon emissions due to cement production be E_p. Then the total emissions E is expressed in equation (1). Then the total emissions E is expressed in equation (1).

$$E = E_b + E_p \tag{1}$$

The carbon emission function due to fuel combustion is shown in equation (2).

$$E_b = \sum_{i=1}^{n} \left(AD_i + EF_i \right) \tag{2}$$

In equation (2), AD_i is the combustion utilization data for the i fuel, EF_i is the carbon emission factor for the i fuel, n is the fuel quantity, and $i = 1, 2, \cdots, n$.

The calculation function of fuel utilization data is shown in equation (3).

$$AD_i = NCV_i \times FC_i \tag{3}$$

In equation (3), NCV_1 represents the average low-level heat of fuel, and FC_1 represents the fuel consumption. The fuel carbon emission factor is calculated from carbon oxidation rate and calorific value, and the calculation function of fuel carbon emission factor is shown in Eq. (4).

$$EF_i = CC_i \times OF_i \times \frac{44}{12} \tag{4}$$

In equation (4), CC_i represents the carbon content per unit calorific value of the fuel, OF_i is the carbon oxidation rate of the fuel, and $\frac{44}{12}$ is the molecular weight ratio of carbon dioxide to carbon. Coal is a commonly used fossil fuel, and the carbon content per unit calorific value and carbon oxidation rate of coal are calculated as shown in equation (5).

$$\begin{cases} CC_{co} = \dfrac{C_{co}}{NCV_{co}} \\ OF_{co} = 1 - \dfrac{G_{cin} \times C_{cin} + G_{ash} \times C_{ash} / \eta_{de}}{FC_{co} \times NCV_{co} \times CC_{co}} \end{cases} \tag{5}$$

In equation (5), G_{cin} denotes the coal slag production, C_{cin} is the average calculated value of slag carbon content in %, G_{ash} denotes the fly ash production, C_{ash} denotes the carbon content in fly ash, and η_{de} denotes the dust removal efficiency of enterprise production. Secondly, the carbon emission in the production of cement enterprises can be expressed as equation (6).

$$E_l = Q \times [(FR_1 - FR_{10}) \times \frac{44}{56} + (FR_2 - FR_{20}) \times \frac{44}{40}] \tag{6}$$

In equation (6), Q denotes the total amount of clinker in current production, is the CaO content in clinker, FR_1, FR_{10} is the non-carbonate decomposed CaO content in clinker, FR_2.is the MgO content, and FR_{20} denotes the non-carbonate decomposed MgO content.

In the GHG accounting in cement enterprises, there will be certain uncertainty in each emission factor under external interference such as instruments in the selection of emission factors, for this reason, the study introduces uncertainty assessment to reduce data bias, and the uncertainty calculation of Monte Carlo method is shown in Figure 3.

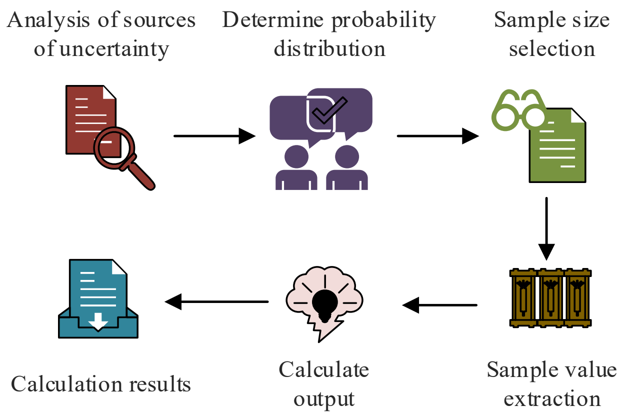

Figure 3. Uncertainty Calculation Process of Monte Carlo Method

It is shown that the Monte Carlo method in the uncertainty calculation will be used to build a suitable mathematical model by sampling random numbers and using this to obtain an approximate solution of the results. The uncertainty affecting the carbon emission factor can be calculated and defined as the uncertainty in the incompleteness of the measurement data, the bias of the measurement instrument, the unreasonableness of the measurement method and the incompleteness of the environmental influences [20-21]. Finally, the uncertainty analysis model of emission factor method is established in equation (7).

$$E_l = FC_{co} \times NCV_{co} \times CC_{co} \times OF_{co} \times \frac{44}{12} + Q \times [(FR_1 - FR_{10}) \times \frac{44}{56} + (FR_2 - FR_{20}) \times \frac{44}{40}] \tag{7}$$

In equation (7), E_l is the carbon emissions of cement enterprises during the verification period.

3.2. DSR-based corporate carbon trading audit evaluation index system

The study proposes the use of GHG accounting for carbon emission monitoring of cement enterprises, based on which, the DSR model is used to further realize the evaluation of carbon trading audit of enterprises. The DSR model is more reflective of the environmental impacts in the economic market than the Pressure State Response model [22]. The basic structure of the DSR model is shown in Figure 4.

Figure 4 shows that there is a significant correlation between driving force, state, and response. "Driving force" refers to the initial factors that cause or promote the carbon emission problem of cement companies. In the DSR model, the driving force is the fundamental cause of environmental problems or environmental changes. Here, it specifically refers to various factors that affect the carbon emissions of cement companies. Driving force can serve as a driving force to cause state indicators to change, and can also serve as a stimulus source to cause response indicators to change. The status indicators will transfer the environmental status as a basis to the response indicators, and then conduct environmental governance through a human approach. Response indicators can change the state of the environment and alleviate driving force indicators. Secondly, to understand the carbon emission results of cement enterprises, it needs to understand the carbon emission sources of cement enterprises in production and manufacturing, as shown in Figure 5.

The carbon dioxide emission sources of cement enterprises are mainly divided into direct emission sources and indirect emission sources. The direct emission sources include carbon dioxide generated from raw materials in cement production, and also include carbon dioxide generated from fuel in manufacturing. In this regard, we analyze the construction path of the enterprise CAE index system for the carbon emission sources in the production of cement enterprises. Firstly, we take the integrated evaluation of enterprise carbon audit as the target layer, the influencing factors of enterprise economy and environmental protection as the second layer, and finally the indexes that need specific evaluation as the third layer, so as to build a perfect enterprise carbon trading audit evaluation index system as expressed in Table 1

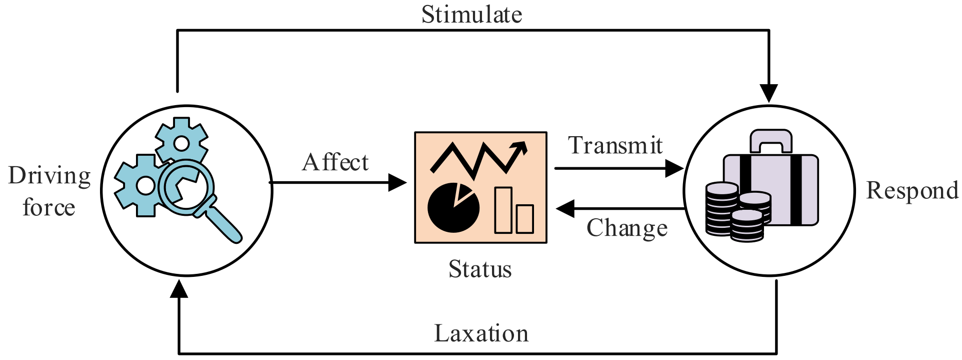

Figure 4. DSR Model Structure

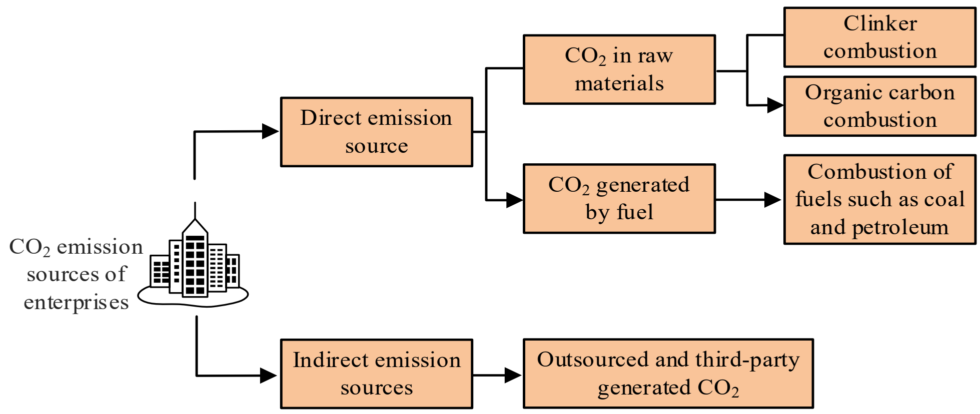

Figure 5. Carbon emission sources in production and manufacturing of cement enterprises

Table 1. Enterprise carbon trading audit evaluation index system

Target layer	Level 1 indicators	Secondary indicators	Indicator nature
Carbon audit and evaluation of cement enterprises	Driving force indicators	Total assets	Quantitative index (+)
		Main business income	Quantitative index (+)
		Product operation volume	Quantitative index (+)
		Total corporate taxes	Quantitative index (+)
	State index	Product carbon dioxide emissions	Quantitative index (-)
		Product nitrogen oxide emissions	Quantitative index (-)
		Product sulfur dioxide emissions	Quantitative index (-)
		Emissions of particulate matter	Quantitative index (-)
		Energy consumption of cement products	Quantitative index (-)
		Degree of implementation of enterprise laws and regulations	Quantitative index (+)
		Clean production degree	Quantitative index (+)
	Response indicators	GHG reduction rate	Quantitative index (+)
		Nitrogen oxide emission reduction rate	Quantitative index (+)
		Sulfur dioxide emission reduction rate	Quantitative index (+)
		Emission reduction rate of particulate matter	Quantitative index (+)
		Coal saving	Quantitative index (+)
		Low-carbon production investment	Quantitative index (+)

For the calculation of index weights in the evaluation index system, the study selects hierarchical analysis as the theoretical basis for weight scoring, and firstly calculates the product of judgment matrix in the weight calculation, see equation (8).

$$m = \prod_{j=1}^{n} a_{ij} \quad (8)$$

In Eq. (8), a_{ij} represents the data of the i row and j column in the judgment matrix. Next, the normalization of the data is performed, and the results are shown in Eq. (9).

$$W = \sum_{k=1}^{n} \sqrt[n]{m_k} \quad (9)$$

Then the maximum characteristic root is calculated by the result of equation (9) as shown in equation (10).

$$\lambda = \frac{1}{n}\sum_{1}^{n}\frac{AW}{W} \quad (10)$$

In equation (10), A denotes the maximum value vector. To verify the scientific and rationality of the evaluation index system, the study proposes to use the consistency test to define the logic of the evaluation index system, and the consistency index CI is as in Eq. (11).

$$CI = \frac{\lambda - n}{n-1} \quad (11)$$

Where, n means the sum of indicators.

Finally, the study chooses the environmental merit value to quantify the results of carbon trading audit evaluation of cement enterprises, which is an environmental performance evaluation method that can quantify the comprehensive monitoring score of a multi-indicator system and can express the environmental situation more objectively. Previous studies have concluded that a smaller value of the environmental merit value indicates a higher level of CER, which is calculated in equation (12).

$$V = \sum_{i=1}^{n} W_i \left(\frac{P_i - U_i}{B_i} \right)^2 \qquad (12)$$

In equation (12), P_i indicates the measured value of environmental performance, U_i indicates the ideal performance value, W_i indicates the weight of indicators in the index evaluation system, and B_i indicates the range of fluctuation of the performance value.

4. Experimental analysis of enterprise carbon trading audit evaluation

4.1. Analysis of the effect of enterprise carbon emission monitoring

The study first proposed a carbon emission monitoring method based on GHG accounting in order to more accurately evaluate corporate carbon trading audits. To verify the performance of the monitoring method in the study, the differences in accuracy and error values of the different methods in the monitoring process were first compared, and the results are shown in Figure 6.

Figure 6(a) shows the difference in monitoring accuracy among the emission factor method, the material balance method, and the actual measurement method. From Figure 6(a), it can be seen that the monitoring accuracy of all three methods showed a growing trend as the number of monitoring times increased continuously. In the comparison of the three monitoring methods, it was found that the monitoring accuracy of the emission factor method used in the study was finally able to stabilize around 99.3%, while the maximum accuracy of the material balance method and the actual measurement method were 98.7% and 99.1%, respectively, which were lower than the stable values of the emission factor method. Figure 6(b) is the results of the difference analysis of the error values of the three monitoring methods in the monitoring test, with the increasing of monitoring times, the monitoring error values of the three methods are decreasing, among which the absolute value of the monitoring error of the emission factor method used in the study can finally be stabilized around 0.1, while the absolute value of the stable error of the material balance method and the actual measurement method are 0.02, which is lower than that of the emission factor method. The absolute value of the stabilization error of both the material balance algorithm and the actual measurement method is 0.02, which is lower than the emission factor method. The above results indicate that the emission factor method used in the study has a high accuracy and low error in carbon emission monitoring.

To further understand the effect of enterprise carbon emission monitoring based on GHG accounting, the study selected 42 cement enterprises for carbon emission accounting analysis. In the process of carbon emission accounting analysis, the study conducted uncertainty synthesis as a way to assess the carbon emissions of cement enterprises in the manufacturing process, and the results were obtained as shown in Table 2.

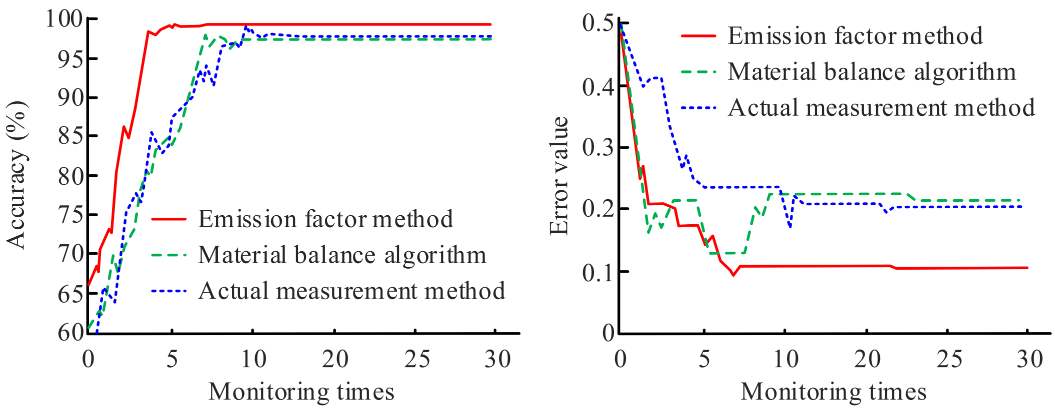

Figure 6. Performance analysis of various monitoring methods. (a) Monitoring accuracy changes; (b) Error value change.

Table 2. Uncertainty of carbon emission accounting

Uncertainty component		Data Combination A	Data Combination B	Data Combination C	Data Combination D
Material weighing	Measured value	0.50%	0.50%	0.50%	0.50%
Lower calorific value	Measured value	/	3.72%	3.72%	3.72%
	Default value	14.0%	/	/	/
Carbon content per unit calorific value	Measured value	/	/	3.85%	3.85%
	Default value	9.64%	9.64%	/	/
Carbon oxygen ratio	Measured value	/	/	/	1.90%
	Default value	6.00%	6.00%	6.00%	/
CaO content in clinker	Measured value	1.00%	1.00%	1.00%	1.00%
Combined relative standard uncertainty		18.10%	12.05%	8.17%	5.76%
Extended relative standard uncertainty		36.21%	24.11%	16.33%	11.52%

From Table 2, the study evaluated and analyzed the carbon emission uncertainties of material weighing, low level heat generation, carbon content per unit calorific value, carbon and oxygen content and CaO content in clinker of cement enterprises, and also proposed different data combinations and analyzed the uncertainties of different data combinations. The results indicate that the uncertainties of carbon emission of various data combinations are significantly different, among which the synthetic relative standard uncertainty and the extended relative standard uncertainty of data combination D are the smallest, i.e., the carbon emission monitoring bias of this data combination is the smallest. Finally, according to the uncertainty calculation results, the carbon emission intensity distribution results of 42 cement enterprises were obtained by combining the carbon emission factor method monitoring as shown in Figure 7.

From Figure 7, there are significant differences in carbon emission intensity among 42 cement enterprises, with the maximum value of carbon emission intensity reaching 1.02 and the minimum value only 0.76. In addition, from Figure 7 that a total of 30 cement enterprises have carbon emission intensity higher than the benchmark value, while only 12 cement enterprises have carbon emission intensity benchmark values. From the current development of China's carbon emissions trading market, if the carbon emissions intensity of enterprises is greater than the benchmark value, enterprises need to purchase quotas in the trading market to meet their carbon emissions status, otherwise they need to reduce the intensity of GHG emissions. Therefore, based on the monitoring results in Figure 7, a total of 30 cement companies need to purchase certain quotas from the carbon trading market to meet their carbon emissions needs.

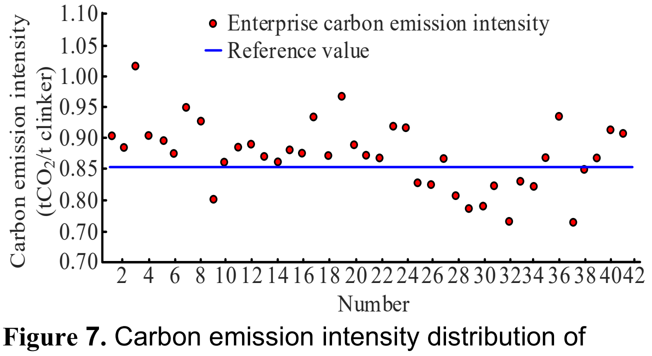

Figure 7. Carbon emission intensity distribution of cement enterprises

4.2. Corporate carbon trading audit evaluation

The study firstly proposes a GHG accounting-based carbon emission monitoring method in carbon trading audit, and learns that when the carbon emission intensity of an enterprise is higher than the benchmark value, it needs to purchase allowances in the carbon trading market to meet its own production needs. In this study, a DSR model was proposed based on the GHG accounting and monitoring to evaluate the carbon trading audit index system. To determine the rationality of the enterprise carbon trading audit index system, the study first determined the index weights in the evaluation index system, and the results are shown in Table 3.

From Table 3, among the CAE index system of cement enterprises, the response index has the largest weight result of 0.540, which indicates that the response index has the most significant influence on the CAE. Among the response indicators, it can be found that the weight of GHG reduction rate is the highest, in addition to the weight of nitrogen oxide reduction rate, sulfur dioxide reduction rate and coal saving amount is above 0.1, while the combined weight of GHG reduction rate and coal saving amount is above 0.1. The above results show that cement enterprises can achieve low carbon production by improving the GHG reduction rate and increasing coal savings of enterprises. In addition, from Table 3 that the weights of the driving force and the state indicator are 0.163 and 0.297, respectively, among which the weight of the state indicator is also larger and has a greater impact on the evaluation of the carbon audit of cement enterprises. Finally, from the calculation results of the indicator weights, we can learn that enterprises need to pay attention to the indicators of driving force, state and response to reduce carbon emissions by adjusting the energy structure and consumption of enterprises in their manufacturing. Secondly, to verify the rationality and feasibility of the carbon trading audit evaluation method proposed by the study, the degree of fit between the CAE based on the DSR model and the actual value was compared and analyzed, and the results are shown in Figure 8.

In Figure 8, the study analyzes the degree of fit between the calculated and the actual simulated values in two scenarios. Figure 8(a) is the results of the fit analysis between the computed and actual values in scenario 1, and the fit value between the computed and actual values reaches 0.933, indicating a high degree of similarity between the computed and actual values. Figure 8(b) is the results of the fit analysis between the calculated and actual values in Scenario 2, and from the figure that the fit value between the calculated and actual values R2 reaches 0.954. The above results show that the CAE based on the DSR model proposed by the research has a high similarity with the actual values, which is reasonable and feasible in the actual evaluation. Finally, the calculated weights of CAE indexes of cement enterprises were standardized and used to obtain the environmental excellence values, through which the integrated evaluation of enterprise carbon emissions was worked out, and the results are shown in Figure 9.

Figure 9(a) shows the trend of the environmental merit value of cement enterprises in the past 5 years. From Figure 9(a), we can see that the evaluation of the environmental merit value of enterprises in the evaluation of carbon trading audit of cement enterprises shows a decreasing trend, indicating that the level of CER of cement enterprises shows a trend of increasing year by year. The main reason is that, influenced by the national call for green production and manufacturing, many cement enterprises began to increase their corporate emission reduction efforts and continuously increase their environmental protection investment, which makes the environment of cement enterprise production line operation smaller and gradually better, thus optimizing the environmental superiority value of the enterprise. Figure 9(b) shows the analysis of the degree of influence of the driver indicator, state indicator and response indicator on the environmental merit value, and it can be seen that the response indicator has the most significant influence on the environmental merit value and remains above 0.04 for a long time. From the above carbon trading audit evaluation results, it can be learned that the cement companies included in the study as a whole are moving toward the trend of CER level improvement, and the results are obvious.

As shown in Figure 10, the study conducts comparisons from three aspects: comprehensive matching degree of carbon audit, corporate economic matching degree and environmental protection matching degree. In terms of the comprehensive matching degree of carbon audit in Figure (a), the DSR algorithm performs well in considering the dynamically changing corporate carbon emission process. Its comprehensive analysis enables it to more accurately assess a company's overall performance in carbon trading and improves matching. In terms of corporate economic matching in Figure (b), the DSR algorithm better understands the relationship between corporate economic behavior and carbon emissions by considering the driving force and response of corporate economic factors. By comprehensively analyzing the economic activities and carbon emissions of enterprises, the DSR algorithm shows better adaptability in terms of matching. In terms of the environmental protection matching degree in Figure (c), the DSR algorithm comprehensively considers the driving forces and responses to environmental protection, which better reflects the degree of concern of enterprises for environmental protection in carbon trading. It can comprehensively evaluate the environmental protection behavior of enterprises and improve the matching degree. Therefore, from the comparison of the three aspects of carbon audit comprehensive matching degree, corporate economic matching degree and environmental protection matching degree, the DSR algorithm shows more superior and comprehensive characteristics compared with the PSR model in carbon trading audit evaluation research.

Table 3. Weight calculation of evaluation index system

Target layer	Level 1 indicators	Weight	Secondary indicators	Subweight	Comprehensive weight
Carbon audit and evaluation of cement enterprises	Driving force indicators	0.163	Total assets	0.463	0.0756
			Main business income	0.177	0.0281
			Product operation volume	0.274	0.0456
			Total corporate taxes	0.087	0.0139
	State index	0.297	Product carbon dioxide emissions	0.272	0.0808
			Product nitrogen oxide emissions	0.183	0.0544
			Product sulfur dioxide emissions	0.183	0.0544
			Emissions of particulate matter	0.099	0.0294
			Energy consumption of cement products	0.104	0.0312
			Degree of implementation of enterprise laws and regulations	0.104	0.0312
			Clean production degree	0.056	0.0160
	Response indicators	0.540	GHG reduction rate	0.304	0.1570
			Nitrogen oxide emission reduction rate	0.139	0.0690

	Sulfur dioxide emission reduction rate	0.139	0.0690
	Emission reduction rate of particulate matter	0.095	0.044
	Coal saving	0.252	0.129
	Low-carbon production investment	0.071	0.032

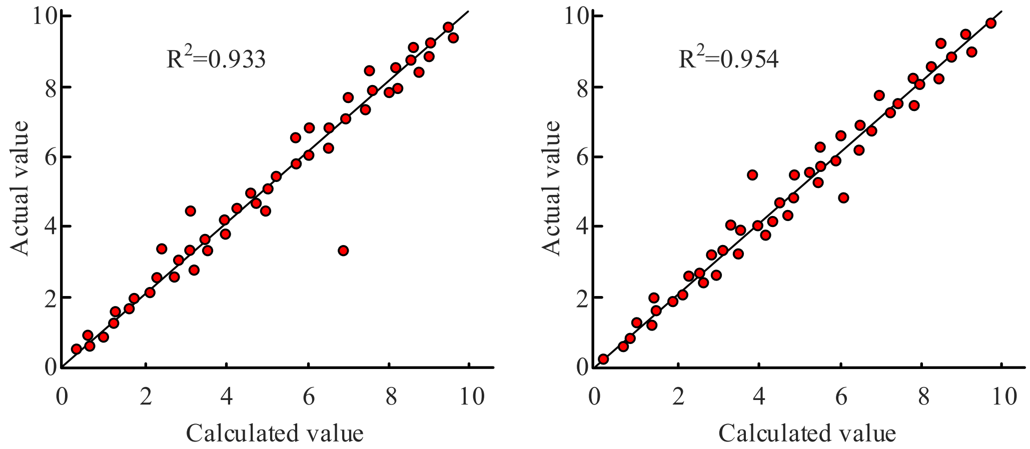

Figure 8. The fitting degree between the calculated value and the actual value of the CAE.
(a) Comparison of simulated values in Scenario 1; (b) Comparison of simulated values in Scenario 2

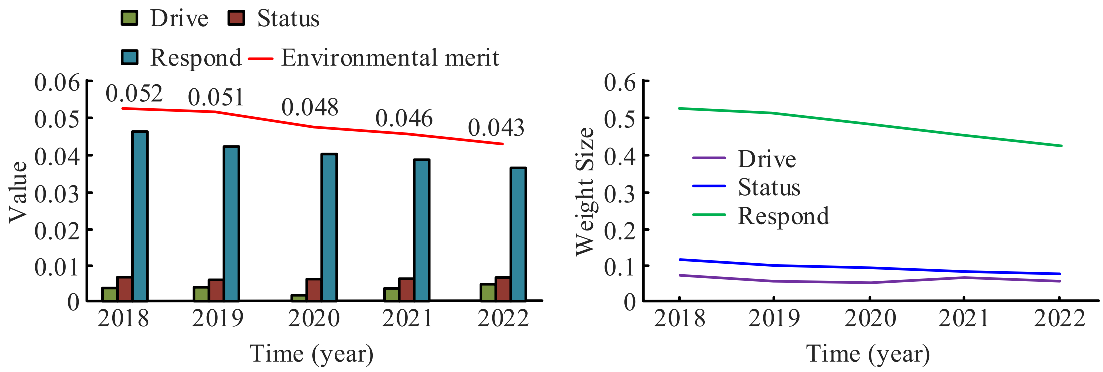

Figure 9. Comprehensive evaluation of enterprise carbon emissions.
(a) Changes in environmental merit; (b) Impact degree of DSR indicators.

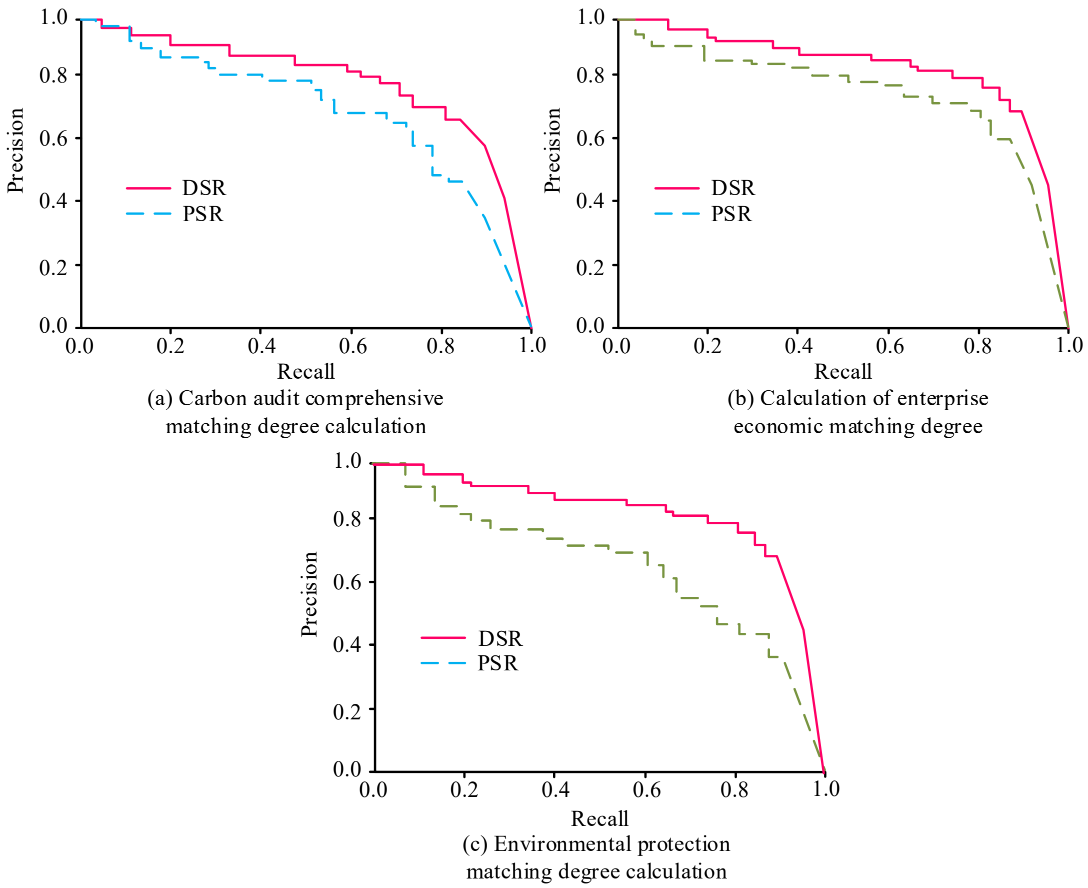

Figure 10. Comparison of algorithm performance of DSR model in carbon trading audit evaluation

5. Conclusion

With the continuous development of social economy, environmental issues are becoming increasingly apparent. How to maintain the coordination of environmental and economic development is an urgent issue to be addressed. This study takes carbon trading as an example, starting with enterprise CAE, proposes a CAE index system that combines DSR model and GHG accounting, and hopes to urge enterprises to reduce carbon emissions during development. The research results indicate that the accuracy of the proposed enterprise carbon emission monitoring method can ultimately stabilize around 99.3% and is higher than the maximum accuracy of the material balance algorithm and the actual measurement method. In addition, the absolute value of the monitoring method error proposed in the study can ultimately be stabilized around 0.1, while the absolute value of the stability error of both the material balance algorithm and the actual measurement method is 0.02. In the carbon transaction audit evaluation, for cement enterprises, the weight result of the response index is the largest, reaching 0.540, which means that the response index has the most important impact on the CAE. At the same time, through the fitting analysis, the fitting degree between the CAE index proposed in the study and the actual value can reach 0.954, which can be used to evaluate the carbon audit of enterprises. According to the CAE of cement enterprises, in recent years, the CER level of cement enterprises has continuously improved, and from the results, it can be learned that the development of CER in cement enterprises can start with response indicators. The above results indicate that combining the DSR model and GHG accounting can effectively complete corporate carbon transaction audits, and thereby derive corporate low-carbon development strategies. However, comparative experiments have not been conducted to further verify the superiority of the evaluation indicator system in the study, so other rating systems will be introduced in subsequent studies to verify the applicability of the evaluation indicator system proposed in the study.

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