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Carbon Audit Evaluation System and its Application in the Iron and Steel Enterprises in China

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Abstract:

China launched its carbon emissions trading market and established a national carbon emissions trading system in 2017, both of which call for accurate carbon audits to reflect carbon emissions of enterprises. Drawing on the carbon audit theory and the driving force-state-response (DSR) model, this paper aims to construct a carbon audit evaluation index system and to analyse the application of the system in the iron and steel enterprises in China. Data was collected from the Statistical Yearbook and the Sustainable Development Report and Financial Report of the iron and steel enterprises in China from 2011 to 2015. Research results show that establishing a carbon audit evaluation index system plays an essential role in implementing carbon audits; the system also improves the corporate carbon auditing system and evaluation mechanism, optimises the enterprise's energy saving and emission reduction process, and makes a positive contribution to a low-carbon economy. The research also identifies several issues in relation to carbon audits in the iron and steel enterprises, including insufficient infrastructure and the shortage of talents for carbon audits, and the lack of innovation in clean production technology and capital investment.

Keywords: Carbon Audit, Index, DSR Model, Carbon Footprint Theory, Iron and Steel Enterprises

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1. Introduction

Carbon audit is a new branch of audit in China. In the iron and steel industry, in particular, there are inadequate carbon audit standards and complex audit data, which complicate auditors' work. It is of importance to establish a concise, comprehensive, and feasible carbon audit evaluation system in enhancing the accuracy of audit results, improving audit efficiency, and promoting carbon audit. A proper carbon audit helps businesses to recognise the vitality of resource utilisation and explore the potential for energy saving. Having a sound system to evaluate carbon audits is also of importance in promoting and developing a low-carbon economy.

This paper, therefore, aims to construct a carbon audit evaluation system based on the driving force-state-response (DSR) model. An analytic hierarchy process is used to categorise the framework of the carbon audit evaluation index system into three factors: the driving force indicator, the status indicator, and the response indicator. The suitability of the indicators is considered in the selection process, with both quantitative and qualitative indicators used.

This remainder of the paper is structured as follows. Section two reviews the extant literature on carbon audit and carbon audit evaluation system. Section three considers the theoretical analysis and conceptual framework. Section four describes the construction of a carbon audit evaluation index system based on the DSR model. Section five presents the application of the system in the iron and steel enterprises in China. The final section discusses and concludes the paper.

2. Literature review

The concept of 'carbon audit' was first proposed in the UK, followed by the Netherlands, the United States and other western developed countries (Wang, 2010). 'Report on the Work Performance of the year 2008-2009', issued by the Environmental Audit Committee of the House of Commons in the UK, is the first comprehensive audit of low-carbon related issues. In 2012, the International Accreditation Standards Board (ISAE3410), issued by the International Board of Auditors and accreditation guidelines, provided the standards for the implementation of carbon audits in tandem with the rationale and the suitability of the standards. Ramírez and González (2011) highlighted the primary role of auditing in the carbon trading process by analysing the main carbon assets of enterprises. Olson (2010) studied the difference between carbon audits and traditional audits, suggesting that companies should produce transparent carbon emissions reports. Li and Yan (2010) studied motivations, targets, contents, current status, and countermeasures with regard to carbon audits. Chen and Mei (2012) argued that the carbon audit, as a branch of environmental auditing, is an essential way for a country to adapt to the transformation of economic development and improve the status and role of national auditing. Wang (2012) proposed that the carbon audit is a new environmental regulation tool to deal with the challenges created by global warming. Harun et al. (2013) introduced a life cycle method to analyse the waste production process, which can be divided into different stages to conduct low-carbon audits. Chen et al. (2013) quantified carbon emissions using the boundary area and base year. Additionally, some researchers have attempted to construct a carbon audit evaluation index system. Tang and Fu (2013), for example, selected 15 carbon audit evaluation indicators from five aspects, including low-carbon output, low-carbon consumption, low-carbon resources, low-carbon environment, and low-carbon policy. Tang and Fu (2013) employed an artificial neural network model to determine the weights of the carbon audit evaluation indexes and the results of the carbon audit. Guan and Tong (2016) used the related theory of performance evaluation and the Vanke Group as an example to establish a carbon audit evaluation index system using fuzzy mathematical analysis.

Carbon footprint (CF), which derives from ‘ecological footprint’, is concerned with the impact of carbon emissions from human activities on the environment. There is, however, no consensus on the definition of ‘carbon footprint’. Post (2006) believed that the carbon footprint refers to the total amount of carbon dioxides and other greenhouse gases emitted during a product’s life cycle. Wiedmann and Minx (2007) viewed the carbon footprint as the total amount of CO_2 emitted by a specific product or service system during its entire life cycle or the total amount of CO_2 emitted directly and indirectly by individuals, organisations, governments and industrial sectors during a performing activity. The PAS 2050 Specification considers the carbon footprint as a term to describe the amount of greenhouse gas (GHG) emissions produced by a particular activity or entity (BSI, 2008). In general, the term “carbon footprint” is used by organisations and individuals to evaluate greenhouse gas emissions in relation to climate change, which include carbon dioxide (CO_2), methane (CH_4), nitrogen oxides (N_2O), and other types of greenhouse gasses such as hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). Brown et al. (2009) suggested that the carbon footprint is an integral part of the ecological footprint analysis and a function of the land area that absorbs greenhouse gases. It can be argued that the carbon footprint defined by Post (2006) is more comprehensive, including emissions of CO_2 and other greenhouse gasses over the life cycle. Finally, many researchers still encounter problems in the determination of the carbon footprint boundary, the selection of carbon emission factors, and the accuracy of data collection. In China, the thermal power, cement, and iron and steel industries are amongst the top energy consumers and air polluters, having significant impacts on climate change (Wang et al., 2018).

Monitorability, reportability and verifiability (i.e. MRV) are the basic requirements of the international community for monitoring greenhouse gas emissions and emission reductions, but also the operation foundations of the national greenhouse gas emission inventory under the United Nations Framework Convention on Climate Change and the three implementation mechanisms under the Kyoto Protocol (i.e. the International Emissions Trading Mechanism, the Joint Implementation Mechanism, and the Clean Development Mechanism). The MRV principle also lays the foundation for many countries to establish their carbon emissions trading systems (Zhang, 2017).

The MRV system quantifies CO_2 emissions by obtaining accurate, comparable, and reliable data, provides a database for the allocation and trade of carbon credits, and ensures efficient operation of the carbon market. The limitations of the MRV system include weak legal and institutional support, the imperfection of technical guidelines and standards, the uneven capabilities of third-party verification agencies.

The advantages of carbon audits are multi-fold: first, to ensure effective energy conservation and emission reduction through a systematic carbon emissions strategy; second, to improve carbon-related decision making; third, to evaluate carbon accounting systems and monitor the effectiveness of energy conservation and emission reduction funds; fourth, to meet local and international low carbon products' legislation requirements; and finally, to better understand company operations, decrease energy consumption and reduce costs. The disadvantages of carbon audits are three-fold. There is a lack of legal basis and audit evaluation criteria for conducting carbon audit work, many enterprises fail to have a good understanding of carbon auditing and carbon information disclosure, and there is a shortage of talents to auditing carbon information.

3. Theoretical Analysis and Conceptual Framework

Carbon audits refer to the auditing practices conducted by auditing agencies according to general audit guidelines and specific carbon audit standards when applicable. These guidelines and standards consider low-carbon project revenue, energy usage, and the fulfilment of responsibilities for energy conservation and emission reduction (Wang, 2012).

The carbon audit is not the same as traditional audits that involve all sectors of the national economy, including industries, organisations and governments at all levels. Instead, the carbon audit focuses on the sources of carbon emissions, including mining, manufacturing, electricity, gas, construction, transportation. The carbon audit focuses on the audit of carbon-derived industries, enterprises, households and individuals. It is different from a traditional audit, which is complex and covers the audits of fiscal and financial revenue and expenditure, the fairness, reliability, relatedness of corporate financial reports, and the review of relevant laws, regulations and internal management.

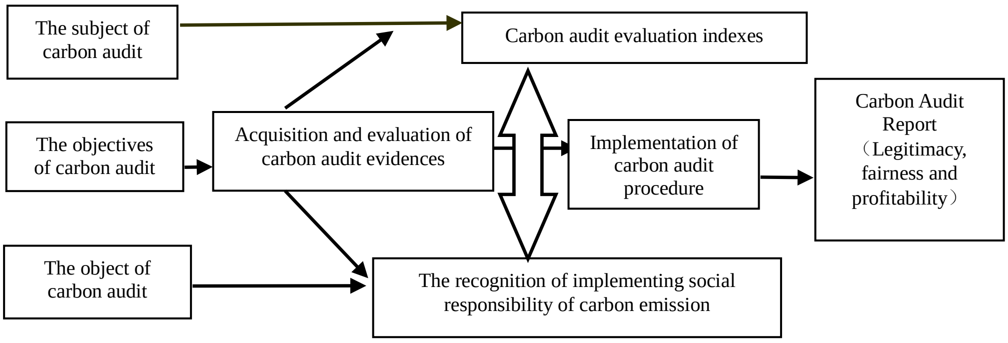
The carbon audit is a tool to measure the greenhouse effect. In this sense, the carbon audit is of importance to national strategies. It integrates economic and social development and indirectly participates in the environmental protection of resources. The carbon audit is a tool to promote resources saving and protecting the environment through audit supervision. The carbon audit is based on the carbon footprint theory, monitoring the total amount of carbon emitted by individuals or groups and providing quantitative analysis indexes and amounts of pollutant emission and a quantitative index for the construction of a carbon audit evaluation system (Hopwood, 2009). The theory confirms and quantifies the carbon emissions of enterprises, internalises external economic effects, and transfers social losses into the operation of individual enterprises to concretise the social responsibilities of the company's carbon emissions. The carbon audit also helps to achieve a coordinated development of environment and economy and the carbon audit target (Lin, 2013).

A complete carbon audit report includes title, recipient, introduction, carbon audit scope, carbon audit opinion, etc. Among these, the introduction should contains the name of the audited carbon emissions information content, related date or covered auditing period, the management's carbon accounting responsibility and the carbon audit personnel's audit responsibility. In addition, there are three aspects should be stated in the part of carbon audit scope. First of all, carbon auditors make plans and perform according to carbon audit basis and standards in order to ascertain whether there is a material misstatement of carbon information reasonably. Besides, audit work includes collecting, identifying and further evaluating carbon audit evidences, for example, carbon emission source sampling, carbon audit evidences examination and so on. Lastly, the carbon audit work can provide a reasonable basis for carbon auditors to express an audit opinion. In terms of the carbon audit result, on one hand, it should explain whether the carbon information disclosure complies with the defined carbon auditing basis and standards promulgated by China, and whether financial statements fairly present the financial position, operating results and cash flows of the carbon emission activities or events of the auditee in all material aspects. On the other hand, the opinion of the result should be signed and sealed by the carbon auditor and carbon audit institution, and other necessary elements can be filled in right position, such as, the name and address of the carbon audit institution and the date of the carbon audit report. Carbon audit report can be divided into four categories, that is, unqualified opinion, qualified opinion, adverse opinion and disclaimer of opinion respectively.

To summarise, the conceptual framework for the carbon audit consists of several essential contents as follows: (1) The subject and object of the carbon audit; (2) Carbon audit evaluation indexes; (3) Carbon audit objectives; (4) Carbon audit evidence; (5) Carbon audit procedures;

and (6) Carbon audit reports (Schmidt, 2009). The relationships between the contents are summarised in Figure 1.

Figure 1: Conceptual framework of the carbon audit



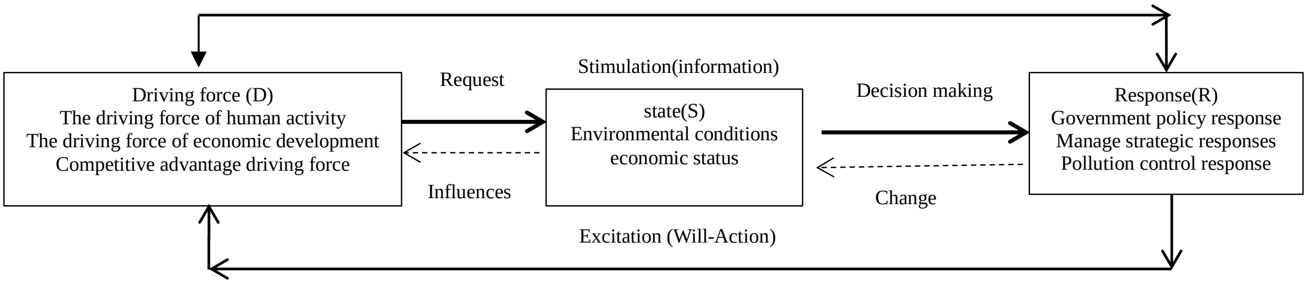
4.Carbon audit evaluation index system based on the DSR model

This section describe the construction of a carbon audit evaluation index system, with regard to the system's foundation and principles and how the indicators are selected.

4.1 The foundation of the carbon audit evaluation index system

The DSR model derives from the Pressure-State-Response (PSR) model. The pressure (P) of the PSR model is replaced with driving force (D), as the PSR model only describes a static environmental problem and has no function of an overall evaluation of sustainable development issues. The improved three-dimensional DSR model, as shown in Figure 2, includes the driving force of the economic or social life (D), the state of resources and the environment (S), and the positive response (R) taken to promote the sustainable development of the economy and society. The DSR model highlights the economic and social impact of environmental issues (e.g. the greenhouse effect) (Wang, 2010). Constructing a carbon audit evaluation index system based on the DSR model can provide appropriate guidance and evaluation to carbon audit work.

Figure 2: Three-dimensional DSR model



4.2 The setting principles of carbon audit evaluation indexes and the selection of evaluation indexes

To implement the carbon audit evaluation effectively, the establishment of indicators follows the principles of being objective and feasible, quantitative and qualitative, having dynamic foresight, combining partial and overall statistics, providing supervision and constraints. Carbon audit evaluation indexes should objectively describe the low-carbon development level of a company during a specified period and adequately reflect the interaction of three significant sub-systems of society within a specified period. The development of any auditing activity is 'process-oriented'. Low-carbon audit evaluations are evaluated in a dynamic time series, which requires that the constructed index system contain static indicators that reflect the current status of the company's low carbon and dynamic indicators that reflect its changing trends. The construction of a low-carbon audit evaluation index system, therefore, should include dynamic indicators set in all dimensions. For example, a low-carbon governance technology innovation investment growth index can be set at both the low-carbon response level and the low-carbon state level. Moreover, indicators including the energy consumption reduction rate of carbon stones and the increasing rate of clean energy consumption can be set. Through comparing and evaluating the current values of these dynamic indicators and values in the base period, the trend of change may be found. The auditors' professional experience can be used to make subjective judgments to infer the nature of audit indexes. The general trend of change can be analysed quantitatively, and enterprises' interrelations with the social, economic and environmental realms are fully reflected in the carbon audit (Ratnatunga and Balachandran, 2009). The carbon audit evaluation index system ought to be designed with multiple parts, including the total energy consumption of enterprises, the impact of low-carbon investment projects, low-carbon investment and other aspects related to corporate data collection and statistics. Supervision and binding principles can guide enterprises to transition to a low-carbon development model. There is a reasonable range of the amount of corporate carbon emissions and energy efficiency. If a low carbon audit evaluation index system concludes that they are beyond this reasonable scope of operation, the stage of low-carbon development is not consistent with sustainable development. The profit-seeking characteristics of enterprises determine that governmental policy incentives and constraints are crucial and indispensable for the low-carbon development of enterprises. Therefore, incentive indicators can be set in the low-carbon index system, such as the support of low-carbon development policies (including government economic incentives). At the same time, standard regulations, policies and technical standards (e.g. compliance indicators of environmental laws and regulations) can be set to provide adequate supervision of corporate carbon emissions and guide enterprises to change to a low-carbon development model (Wang and Li, 2016).

The driving force-state-response (DSR) model was proposed by the UN Commission on Sustainable Development (UNCSD). It is based on sustainable development and there is a clear causal relationship. The basic idea is that the ‘driving forces’ of economic and social activities have changed the ‘state’ of natural resources and the environment in the context of environmental change, and that, accordingly, humans will adopt a series of measures to respond to improve and adjust the sustainability of internal and external systems. From that point of view, the evaluation of the model covers three dimensions: the driving force of the human economy or social life (D); the adverse state of resources and the environment (S); and the positive response humans must take to achieve sustainable economic and social development in this situation (R). Based on the DSR model, this paper constructs a DSR model suitable for low carbon audit evaluation. From the perspective of constructing quantifiable indicators, the factors that constitute the driving force-state-response (DSR) model include: (1) Driving Force. The carbon audit is mainly driven by social, economic and environmental factors. The specific indicators of driving force in the DSR model include total operating income, total assets and total energy consumption of enterprises. (2) State. The state factor of the DSR model includes the development state of a low-carbon economy, including strategic implementation and energy consumption. Specific indicators of the state in the DSR model include the amount of major greenhouse gas emissions, the emission amount of major solid pollutants, comprehensive energy consumption per RMB 10,000 output value, the procurement ratio of clean energy, the benefits of low-carbon related projects, the improvement of the company’s low-carbon development plan and compliance with legislation and laws. (3) Response. Relevant policies and improvements are introduced for the implementation of the carbon audit. The response factor of the DSR model is the governance response policies in the context of high pollution and high consumption loss, the specific indicators of which are savings from using fuel, major greenhouse gas emission reductions, emissions of major solid pollutants, and low-carbon project revenue. The above indicators can be divided into qualitative and quantitative categories, as shown in Table 1 and Table 2.

Table 1: Classification of quantitative and qualitative indicators

Quantitative indicators	Qualitative indicators

Total revenue, total assets, total energy consumption of enterprises,major greenhouse gas emission reductions, emission reductions of major solid pollutants, revenue from low-carbon related projects, perfection of low-carbon development plan of enterprises,the comprehensive energy consumption of 10,000 yuan output value, the proportion of clean energy procurement, fuel-efficient application, major greenhouse gas emissions, emission reduction of major solid pollutants, benefits from low-carbon projects.	Compliance with laws and regulations, investment in publicity and education of low-carbon audit

Note:(1) The comprehensive energy consumption of 10,000 yuan output value = the annual comprehensive energy consumption of the enterprise / the annual output value of 10,000 yuan of the enterprise (%). (2) The proportion of clean energy procurement = total amount of annual purchases of clean energy/total amount of annual purchases of enterprise energy (%). (3) Major greenhouse gas emission=total greenhouse gas emissions in the previous year - total greenhouse gas emissions in the current year. (4) Emission reduction of major solid pollutants = total discharge of major solid pollutants in the previous year - total discharge of major solid pollutants this year.

Table 2: Stratification of the index system

Target layer	Factor layer	Index layer
Comprehensive evaluation index of carbon audit in enterprises	Driving force indicators	Total revenue, total assets, total energy consumption of enterprises
	Status indicators	Major Greenhouse Gas Emissions, Major Solid Emissions, Low-Carbon Related Project Revenues, Perfection of enterprise Low-Carbon Development Plan, Comprehensive Energy Consumption per MW Output, Compliance with Carbon Audit Law, Proportion of Clean Energy Purchases
	Response indicators	Savings from using fuel, major GHG emission reductions, emission reductions of major solid pollutants, benefits from low-carbon projects, investment in the publicity and education of low-carbon audits

5.The Application of a carbon audit evaluation index system based on the DSR model in the iron and steel enterprises

5.1 Research methods and Data Sources

The research methods used in the paper include: (1) Document reading method. (2) A combination of theory and case. (3) A combination of qualitative and quantitative methods. Considering the practicalities of carbon audits, a carbon audit evaluation system was constructed by qualitative and quantitative methods. (4) Analytic hierarchy process.

Considering data sources, the quantitative index data was collected from the Sustainable

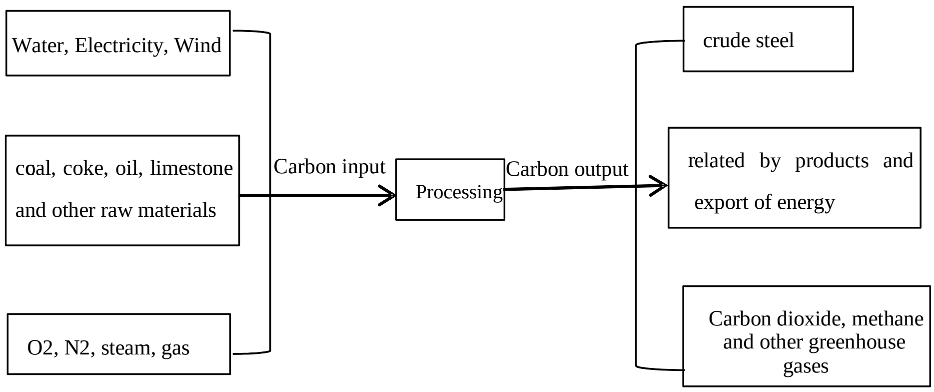
Development Report and Financial Report of the iron and steel enterprises in China and the Statistical Yearbook from 2011 to 2015. Other qualitative indicators are scored by experts.

5.2 The carbon footprint of iron and steel enterprises

5.2.1 Analysis of material input-output in each process of iron and steel enterprises

The process of turning raw materials into products is the process of putting fuel (e.g. coal, oil, and electricity), power, auxiliary raw materials and raw materials into the production process. After the input and output of each process, these raw materials are converted into products and by-products. Some raw materials become recyclable fuels, with CO_2, CH_4, and N_2O discharged into the atmosphere. Greenhouse gasses are generated at each stage and eventually leave the system in the form of contaminants (Gao et al., 2015). The material input-output analysis model of each process involved in the iron and steel enterprises is summarised in Figure 3.

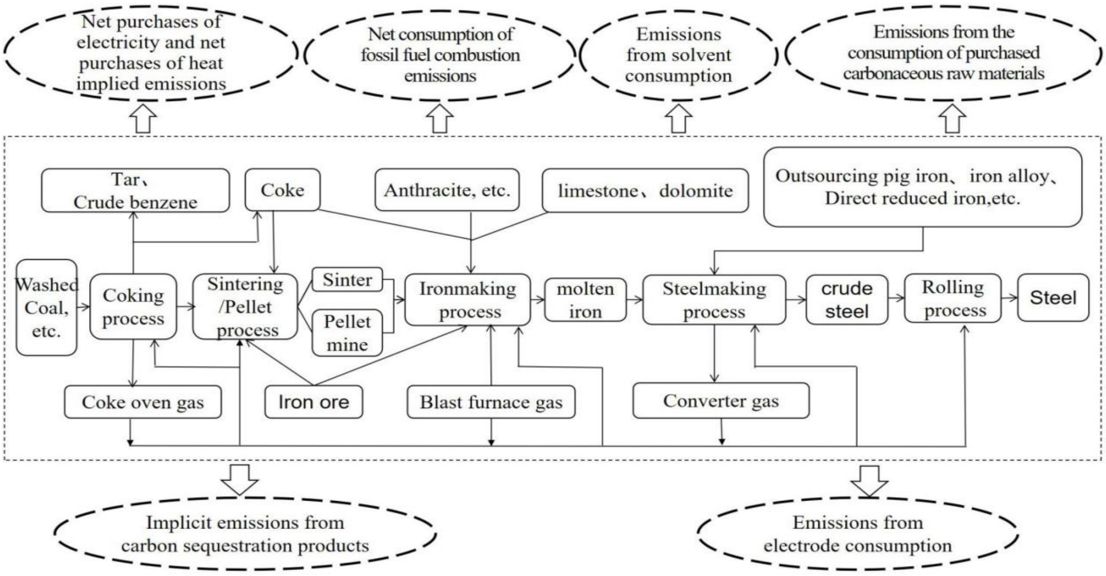
Figure 3: Model diagram of material input-output analysis of every process of the iron and steel enterprises



5.2.2 The boundary analysis of the carbon footprint system of the iron and steel enterprises

The production process of the iron and steel industry is an open and irreversible complex process system. Also, it is a complex iron-coal chemical production system, which transforms natural resources into steel products or waste products through a series of physical and chemical changes. Carbon-containing energy is processed and transformed into an energy product. In general, the sources of the carbon footprint produced during the steel production process include the carbon footprint of raw materials, the carbon footprint of direct energy consumption, the carbon footprint of outsourcing electric heating and the carbon footprint of auxiliary raw materials for industrial processes. In view of the diversity of steel products and the high proportion of carbon emitted from energy sources, and in order to analyse the key issues in a more detailed and systematic way, the carbon footprint of direct energy consumption (a major contributor to the carbon footprint of the steel production process), along with the carbon footprint of part of auxiliary raw materials, are generally selected as the main content (Wang, 2012). A boundary map of the carbon footprint system of iron and steel enterprises is shown in Figure 4.

Figure 4: System boundary of carbon footprint study in iron and steel enterprises



5.3 Analysis of carbon audit process in the iron and steel enterprises

Combined with the basic procedures of general audit work, this paper maintains that there are three stages in the carbon audit process in the iron and steel enterprises: (i) collecting audit evidence of carbon emissions from enterprises, (ii) drafting working papers, and (iii) compiling a report on the carbon audit work. Audit institutions can work together with audit project personnel, environmental protection departments, legal departments and other departments to carry out on-site verification of the iron and steel enterprises, while implementing control tests and substantive procedures to collect reliable and sufficient audit evidence. Such evidence includes a review of records of carbon emission reductions in iron and steel enterprises, analysis of the authenticity of carbon revenues and expenditures, analysis of the rationality of capital investment in various types of low-carbon projects and analysis of the legitimacy of the low-carbon economy reflected in the enterprises' financial data. The carbon audit working paper is the directly written record of the carbon audit evidence from the iron and steel enterprises. It records the methods adopted by the iron and steel enterprises in conducting the carbon audit, the evidence collected, the reference to the internal audit results of iron and steel enterprises and the final audit conclusion. Compared with a general financial audit, the carbon audit working paper focuses more on greenhouse gas statistics, the scope and consumption of carbon fuels and any problems encountered in the carbon emission reduction projects of the enterprises. To meet the demands of government agencies and other stakeholders, the phase of the carbon audit report is launched after the implementation of the carbon audit. The main contents of this phase include drafting carbon audit reports for iron and steel enterprises, soliciting opinions on the carbon audit, revising and submitting carbon audit reports, reviewing carbon audit reports, and obtaining carbon audit conclusions.

5.4 Construction of carbon audit evaluation index system in the iron and steel enterprises

5.4.1 The establishment of the hierarchical model

A carbon audit evaluation index system of the iron and steel enterprises is constructed using the above evaluation indicators of the carbon audit in tandem with the understanding of the current status of the iron and steel industry and the characteristics of a carbon footprint. A hierarchical model can be drawn using the AHP method shown in Figure 5.

5.4.2 Construction of judgment matrix and weight assignment

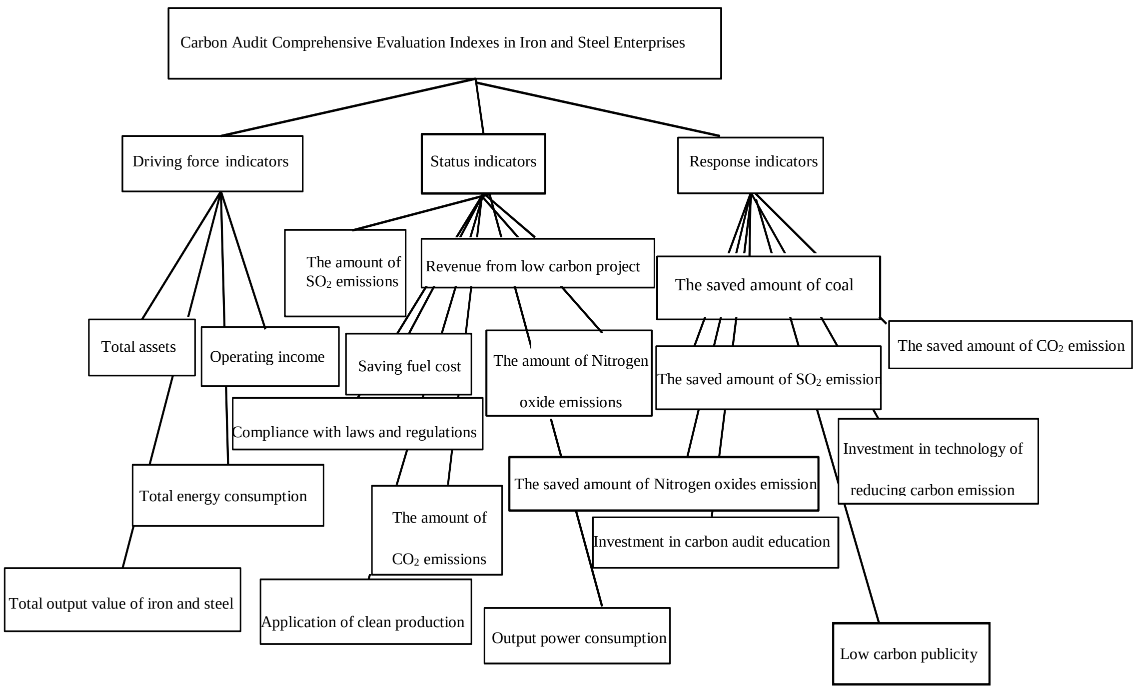
Through analysing the current situation of iron and steel enterprises and the characteristics of energy consumption and utilisation, it is found that whether iron and steel enterprises adopt clean production methods is a significant indicator of the carbon audit evaluation in iron and steel enterprises. The management and monitoring of GHG emissions (e.g. CO_2 and SO_2), therefore, should be considered cautiously in the process of conducting carbon audits for iron and steel enterprises. Energy consumption focuses on traditional coal, oil, and natural gas, exerting significant pressure on the energy-saving and emissions-reduction targets of iron and steel enterprises. Many academics (e.g. Hao et al., 2015) have suggested that it be imperative to cultivate low carbon technology personnel, advocate the development and utilisation of low carbon technology, and save the cost of fuel in the enterprises. Extending this, the relevant indexes in the carbon audit evaluation index system are sorted in order of importance, and the corresponding weights are assigned to the present characteristics of iron and steel enterprises in this paper. The judgment matrix corresponding to the carbon audit evaluation of the iron and steel industry is scored by experts. The weight of each index is then obtained by calculating and normalising the characteristic vector. Finally, the validity and consistency of the weights are tested for the judgment matrix.

The basic ideas are as follows：

(1) Order of the importance of the indexes. According to the actual conditions of iron and steel enterprises, these enterprises attach great importance to the application of technology transformation and cleaner production. As a result, the ranking of the importance of relevant low-carbon knowledge and the training of low-carbon technicians should be in a relatively

higher position in the response indicator layer. Additionally, the energy consumption of iron and steel enterprises is principally caused by the production of power supply and heating, while power and thermal energy consumption mainly comes from the direct combustion of coal and other energy sources in the production field. The CO_2 emissions, SO_2 emissions, and nitrogen oxide emissions, along with the overall energy consumption should be prioritised in the ranking system.

Figure 5: Graphic of the hierarchical structure model



(2) Weight assignment correction. As the implementation of clean production, low-carbon technologies and the direct emissions of greenhouse gases is important in the carbon testing of iron and steel enterprises, the valuation of the weights should be higher than that of the general indicators. Meanwhile, based on some less significant indicators, the weight should be appropriately reduced.

Given the above method of weight assignment, a judgment matrix is constructed corresponding to the carbon audit evaluation in the iron and steel enterprises, and then the consistency ratio of the matrix is calculated according to the calculation results of the formula $CI = (\lambda_{max} - n) / (n-1)$ (n is the order of the judgment matrix and λ_{max} is the maximum eigenvalue of the matrix) and $CR = \frac{CI}{RI}$ (RI is a random consistency indicator) and the consistency ratio of each index is finally solved. The specific contents are presented in Table 3.

Table 3: Carbon audit indicators in the iron and steel enterprises

Carbon Audit Indicators in the Iron and Steel enterprises	Judgment Matrix Consistency Ratio	Whether to Meet the Consistency Requirements
Comprehensive evaluation index	0.0516	YES
Driving force indicators	0.0000	YES
Status indicators	0.0327	YES
Response indicators	0.0414	YES

Table 4 is the evaluation matrix included the comprehensive evaluation index of the carbon audit in the iron and steel enterprises. The consistency ratio of the judgment matrix is 0.0516, which satisfies the consistency requirement. Table 5 is the driving force indicator judgment matrix. The weight of the driving force indicator to the total goal is 0.1958. Meanwhile, the consistency ratio of the judgment matrix is 0.0000, which satisfies the consistency requirement. Table 6 is the status indicator judgment matrix. Then, its weight to the total target is 0.4934, and the consistency ratio of the judgment matrix is 0.0327, which meets the conformance requirement. Table 7 is the matrix of response indicators. The weight of the response indicators to the total target is 0.3108. The consistency ratio of the matrix is 0.0414, and the consistency requirement is satisfied.

Table 4: Comprehensive evaluation indicators of the carbon audit in the iron and steel enterprises

Comprehensive evaluation indicators of carbon audit in iron and steel enterprises	Driving force indicators	Status indicators	Response indicators	Wi weight
Driving force indicators	1.0000	0.5000	0.5000	0.1958
Status indicators	2.0000	1.0000	2.0000	0.4934
Response indicators	2.0000	0.5000	1.0000	0.3108

Table 5：Driving force indicators judgment matrix

Driving force indicators	Total assets	Total output value of iron and steel	Total energy consumption of enterprises	Operating income	Wi weight
Total assets	1.0000	0.2000	0.2000	1.0000	0.0833
Total output value of iron and steel	5.0000	1.0000	1.0000	5.0000	0.4167
Total energy consumption	5.0000	1.0000	1.0000	5.0000	0.4167
Main business income	1.0000	0.2000	0.2000	1.0000	0.0833

Table 6：Status indicators

Status Indicators	SO_2 emissions	Low-carbon project revenue	Fuel-saving cost	Nitrogen oxide emissions	Compliance with laws and regulations	Output value comprehensive power consumption	Application of clean production	CO_2 emissions	Wi weight
SO_2 emissions	1.0000	5.0000	5.0000	1.0000	1.0000	1.0000	0.5000	1.0000	0.1403
Low-carbon project revenue	0.2000	1.0000	1.0000	0.1667	0.1667	0.1667	0.2000	0.2000	0.0286
Fuel-saving cost	0.2000	1.0000	1.0000	0.2000	0.2000	0.2500	0.1667	0.2500	0.0316
Nitrogen oxide emissions	1.0000	6.0000	5.0000	1.0000	4.0000	1.0000	0.5000	1.0000	0.1707
Compliance with laws and regulations	1.0000	6.0000	5.0000	0.2500	1.0000	1.0000	1.0000	1.0000	0.1316
Output value comprehensive power consumption	1.0000	6.0000	4.0000	1.0000	1.0000	1.0000	0.5000	1.0000	0.1396
Application of clean production	2.0000	5.0000	6.0000	2.0000	1.0000	2.0000	1.0000	2.0000	0.2213
CO_2 emissions	1.0000	5.0000	4.0000	1.0000	1.0000	1.0000	0.5000	1.0000	0.1364

Table 7：Response indicators judgment matrix

Response indicators	The saved amount of coal	The saved amount of CO_2 emission	The saved amount of SO_2 emission	The saved amount of Nitrogen oxides emission	Low carbon publicity	Investment in carbon audit education	Investment in technology of reducing carbon emission	Wi weight
The saved amount of coal	1.0000	1.0000	2.0000	2.0000	2.0000	3.0000	5.0000	0.2350

The saved amount of CO_2emission	1.0000	1.0000	1.0000	1.0000	5.0000	5.0000	5.0000	0.2364
The saved amount of SO_2 emission	0.5000	1.0000	1.0000	1.0000	3.0000	6.0000	5.0000	0.2043
The saved amount of Nitrogen oxides emission	0.5000	1.0000	1.0000	1.0000	2.0000	2.0000	2.0000	0.1446
Low carbon publicity	0.5000	0.2000	0.3333	0.5000	1.0000	1.0000	3.0000	0.0773
Investment in carbon audit education	0.3333	0.2000	0.1667	0.5000	1.0000	1.0000	1.0000	0.0565
Investment in technology of reducing carbon emission	0.2000	0.2000	0.2000	0.5000	0.3333	1.0000	1.0000	0.0461

5.4.3 Hierarchical Order

Tables 5, 6 and 7 illustrate the weights of the driving force layer, the status layer, and the response indicator layer, respectively. The three weights are the basis for calculating composite weights, vital for analysing the impacts of each indicator on the overall goals of iron and steel enterprises. The influence of driving force factors on the carbon audit evaluation is conducive for understanding the deficiencies of the carbon audit in iron and steel enterprises. The weight of the criterion layer corresponding to the status indicator can be used to evaluate the importance attached by the iron and steel enterprises to the development of the carbon audit. In addition, the criterion layer also reflects the relevant problems that the iron and steel enterprises should focus on developing the carbon audit and other low-carbon economic activities. The weight of the response indicator layer to the overall goal can be better to promote the implementation of carbon audit work in iron and steel enterprises and help enterprises to make low-carbon decisions. The carbon audit evaluation of iron and steel enterprises can be fully understood by combining the weights of these three layers of factors. The final weight for comprehensive indicators is shown in Table 8. The weight order is as follows: application of clean production > NO_x emissions > total output value of iron and steel > total energy consumption > the saved amount of CO_2 emission > the saved amount of coal > the amount of SO_2 emissions > output power consumption > the amount of CO_2 emissions > compliance with laws and regulations > the saved amount of SO_2 emission > the saved amount of nitrogen oxides emission > investment in carbon audit education > low carbon publicity > operating income > total assets > saving fuel cost > investment in carbon emission-reducing technology > revenue from low-carbon project.

Table 8: The Final weight of carbon audit indicators

Options	Weights
Revenue from Low-carbon project	0.0141
Investment in the technology of reducing carbon emission	0.0143
Saving fuel cost	0.0156
Total Assets	0.0163
Operating income	0.0163
Low carbon technical personnel training	0.0176
Investment in carbon audit education	0.024
The saved amount of Nitrogen oxides emission	0.0449
The saved amount of SO_2 emission	0.0635
compliance with laws and regulations	0.0649
the amount of CO_2 emissions	0.0673
Output power consumption	0.0689
the amount of SO_2 emissions	0.0692
the saved amount of coal	0.073
The saved amount of CO_2 emission	0.0735
Total energy consumption	0.0816
Total output value of iron and steel	0.0816
The saved amount of Nitrogen oxides emission	0.0842
Application of clean production	0.1092

5.5 Discussion

As an intensive energy-consuming and carbon-emitting industry, iron and steel manufacturing is vital for meeting the energy conservation and CO_2 emission reduction targets of China (Zhang et al., 2018). The carbon audit, however, is still under development that lacks uniform standards at the international level. It is different from a traditional audit, which has a complete and mature regulation system including ‘audit law’, ‘independent auditing standards’ and ‘internal auditing standards’. In addition to traditional audit methods such as examination, observation, inquiry, correspondence and analysis in the fields of economics and management, the carbon audit methods rely more on non-economic management disciplines, such as environmental science, ecology, mechanical engineering and geophysics. Crosscutting knowledge emphasises the audit philosophy and methods of the entire factor, the entire process and the entire life cycle. Reports on the carbon audit can be combined with traditional audit reports, so that, special audit reports can be issued. They are flexible, diverse and non-exclusive. In this situation, there is not uniform in format or content.

Through comparing the emission reduction targets of the above-mentioned enterprises and combining the role of the driving force index with the response index in the carbon audit evaluation index of the iron and steel enterprises, this paper analyses the factors that lead to the increase and decrease of the carbon emissions of enterprises and obtain the carbon audit conclusions. The influence of the three factors noted above on the overall evaluation is ranked according to the weight of the indicators: status indicator, response indicator and driving force indicator. The status indicator ranks first, as it is the most important factor of the contribution rate, and the improvement of the indicator is inseparable from the other two indicators. Status indicator mainly includes gas and solid pollutant discharge indicators, low-carbon project fund returns indicators and some policy-related indicators. Among them, gas and solid pollutant emission indexes have an important evaluation function to the development of an enterprise’s carbon audit, because the pollutants that cause environmental damage mainly come from fossil energy consumption in industrial production. In addition, the functions of low-carbon project cost-benefit indicators are apparent. Enterprises take scientific approaches to invest in low-carbon technologies to achieve the effective allocation of resources and sustainable development. The response indicator reflects the measures taken by enterprises in the face of the current implementation of the carbon audit, and they are thus ranked second. Among them, carbon emissions reduction, low carbon publicity, low carbon project investment and other indicators are the direct basis for evaluating whether enterprises attach importance to the development of a low-carbon economy and whether they make low-carbon management and decisions (Zhao, 2014). The rise of enterprise assets in the driving indicator can gradually promote the development of low-carbon enterprises and has impacts on the carbon audit work. However, if the consumption of fossil fuels is increasing and the energy consumption demand is not well controlled, the carbon audit work will be hindered.

5.5.1 Analysis of emission factors

Figure 6: Total energy consumption in the iron and steel enterprises (million ton)

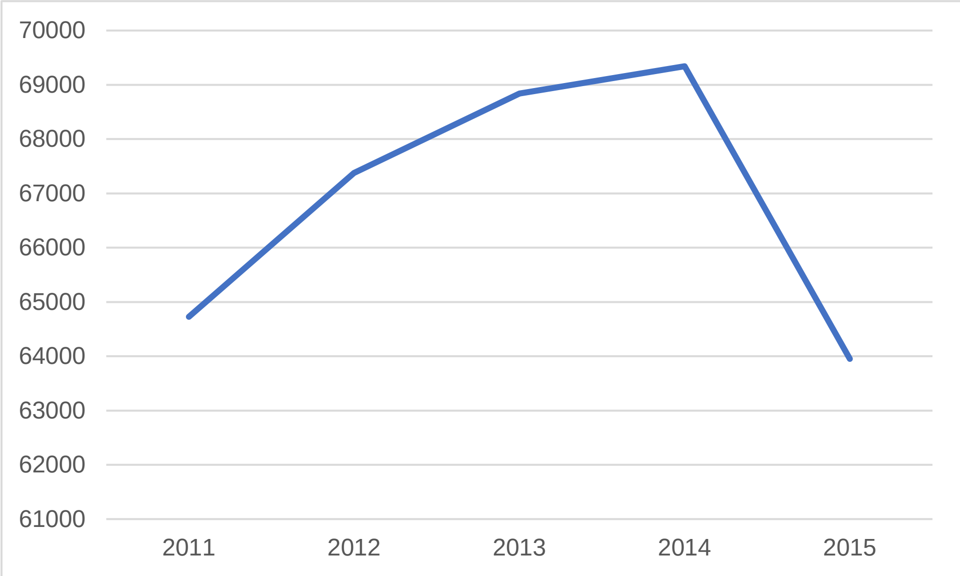
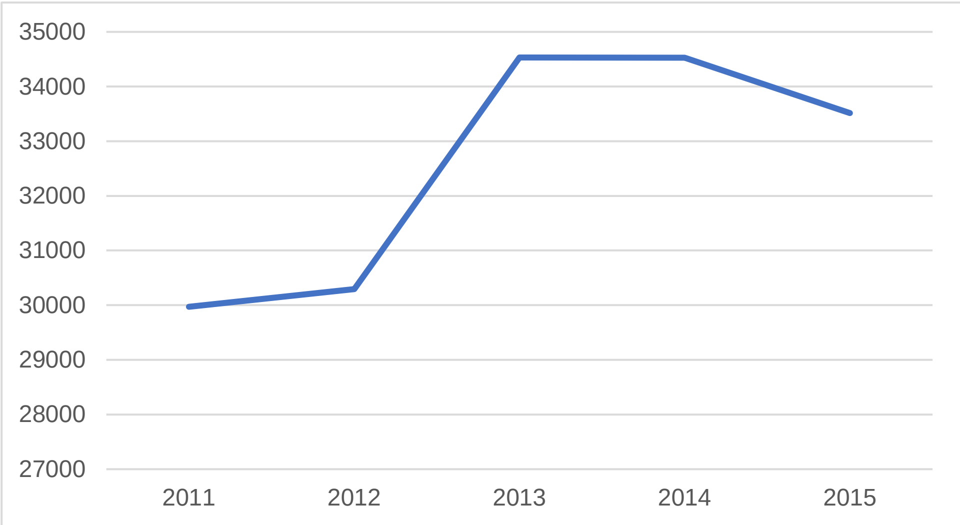


Figure 7: Total coal consumption in the iron and steel enterprises (million ton)



Note: The data in Figure 6 and Figure 7 are from the National Statistical Yearbook (2017)

In the driving force indicators, the weights of the coal output and total energy of the sub-indicator enterprises are prominent; therefore, it can be found that the coal output and the total energy output of iron and steel enterprises can directly affect the carbon emissions of these enterprises. Furthermore, there is no doubt about the role of the carbon audit in supervising the carbon emissions of the iron and steel enterprises. Figures 6 and 7 respectively reflect the total energy consumption and coal consumption of the iron and steel enterprises during the years from 2011 to 2015. Although the total energy consumption and total coal consumption of China's iron and steel enterprises declined in 2015, in general, energy and coal consumption are still enormous. Therefore, under the supervision of the carbon audit, iron and steel enterprises should improve the efficiency of their fuel use, reduce their total consumption of coal, and try to use coal substitutes in their production processes to realise carbon balance with the natural environment. This balance will help the iron and steel enterprises to embark on a green and sustainable development path in the future.

5.5.2 Analysis of emission reduction factors

In the state indicators, the weight of CO_2 emissions, SO_2 emissions, NO_x emissions, the overall energy consumption of output value and application of clean production are highlighted. At the same time, in the response indicators, the weights of sub-indicators (the saved amount of coal, the saved amount of CO_2 emissions, the saved amount of SO_2 emissions, the saved amount of nitrogen oxides emissions) are outstanding, which shows that the iron and steel enterprises should pay attention to CO_2 emissions, SO_2 emissions, and nitrogen oxide emissions in the process of conducting carbon audit work and strengthening cleaner production efforts to save the use of coal. Investment in low-carbon project funds and the training of low-carbon technical personnel play essential roles in the development of energy-savings and emissions reduction. Investment in low-carbon technological innovation will help to complete a carbon audit efficiently, promote the optimization of the enterprise's internal industrial structure, and promote the industrial system.

6.Conclusions and future research directions

6.1 Conclusions

The carbon audit in iron and steel enterprises is a complex system composed of various economic activities such as carbon measurement, energy utilisation, financial analysis, environmental governance and low-carbon production. Because of its characteristics of dynamism and professionalism, it is affected by the quality of internal audits and the degree of integration, as well as by external audit. In order to better reflect the key factors of the carbon audit in iron and steel enterprises, the indicators are divided into different dimensions according to the weighting analysis and the carbon emissions of the iron and steel enterprises mentioned above, which can make an overall appraisal of the carbon audit's technological, financial, internal management and external benefits. In this paper, the dimensions of carbon audit evaluation include the ability of the iron and steel enterprises to reduce carbon emission, the technical benefit of carbon emission reduction, the internal management ability of the enterprises, the ability of the carbon audit staff in the enterprises, the ability of the enterprise in learning and developing and the social and economic benefits brought by the iron and steel enterprises in reducing emissions. The specific classifications are as shown in Table 9. Moreover, it can be seen from Table 10 that iron and steel enterprises pay more attention to the social and technical benefits of carbon emissions reduction in the process of carbon audit evaluation.

Table 9: Carbon audit evaluation dimensions in iron and steel enterprises

Carbon audit evaluation dimensions	Indexes
Enterprise carbon emission reduction investment ability	Low carbon project benefits
	Low carbon project capital investment
Technical benefits of carbon emission reduction in enterprises	Saving fuel costs
	Nitrogen oxides emission reductions
	SO_2 emission reduction
	Save on the amount of coal used
	CO_2 emission reductions
Internal management capabilities	Total assets
	Operating income
	Enterprise coal production
The ability of the carbon audit staff in the enterprise	Low-carbon technical personnel training
The ability of the enterprise in learning and developing	Compliance with laws and regulations
	Low carbon promotion
Corporate social efficiency of emission reduction	CO_2 emissions
	Comprehensive energy consumption of output value
	SO_2 emissions
	Total energy consumption of enterprises
Economic benefits of reducing emissions by enterprises	Clean production application

Table 10: Table of comprehensive analysis weight

Evaluation dimension	Enterprise carbon emission reduction investment ability	Enterprise carbon emission reduction technology benefits	Internal management capabilities	The ability of the carbon audit staff in the enterprise	The ability of the enterprise in learning and developing	Corporate social efficiency of emission reduction	Economic benefits of reducing emissions by enterprises
Weight	0.0284	0.2705	0.1178	0.0176	0.0889	0.3662	0.1092

Although the current carbon audit has received the attention of most iron and steel enterprises, the external benefits of carbon emission reductions still lag behind. There are some shortcomings in the internal assurance of iron and steel enterprises, such as the shortage of carbon audit-related personnel and technological innovation in cleaner production, insufficient system construction and capital investment. The carbon audit evaluation of the iron and steel enterprises can audit the current situation of carbon emissions, discover problems in carbon emissions and identify gaps in expected carbon emission reduction, analyse the causes of problems or gaps and provide the basis for further improving the energy structure of the iron and steel enterprises. According to the factor layer of the DSR model, a comprehensive carbon audit evaluation index model is constructed, and the AHP method is used to set the weights of the carbon audit evaluation indexes of steel enterprises, which can identify problems about the carbon audit of the iron and steel enterprises.

Drawing on the DSR model and the basic auditing theory, this paper constructs a carbon audit evaluation index system to analyse the application of the proposed carbon audit evaluation index system in iron and steel enterprises and draw the following conclusions：

(1) The carbon footprint theory is the primary theoretical basis for the development of the carbon audit and the selection of evaluation indexes, while the construction of the carbon audit evaluation index system is an essential link in the implementation of the carbon audit.

(2) The iron and steel industry is characterised by high energy consumption, pollution, and capital investment. The industry has a high degree of correlation with other industries. It is helpful to study the carbon audit in iron and steel enterprises to guide the carbon audit work in other industries. Therefore, it is necessary and feasible to construct the carbon audit evaluation system roundly, and we need to build a carbon audit evaluation index system according to the principles of objectivity, feasibility, supervision and dynamic foresight to comprehensively audit and evaluate the present situation and future of iron and steel enterprises.

(3) In order to ensure the validity of the index system of the carbon audit, it is necessary to use the relevant model to design and select the indexes. As audits in different industries have clear auditing standards, the evaluation index of the carbon audit usually has some flexibility. Based on the DSR model, this paper designs a carbon audit evaluation index system, combined with the principle of "target layer - criterion layer - indicator layer", from the aspects of the driving force, state and response of iron and steel enterprises, and also takes the iron and steel enterprises as an example to test the representativeness and rationality of the indexes. At the same time, the importance level of each index of the carbon audit is evaluated by the AHP method and a consistency test sorts the weight.

(4) Carbon audit can not only facilitate the coordinated development of the current environment and economy, but also push economic development toward superior quality in China. However, However, there is still a long way to go in the development and full

implementation of China's carbon audit.The most significant reason is the slow pace of construction about China's carbon trading market,the reasons of which can be explained as follows. Initially, the relevant policies and regulations for carbon trading have not yet been perfected and its regulatory system also has been incomplete in China. In this situation, there is a widely existing phenomena that audit work cannot be finished on time, and then the light punitive measures imposed have been no deterrent. Then, it has not yet recognized that carbon audit is the vital supporting factor in the carbon trading system.And the understanding of the important role of carbon trading has not yet been popularized. It has not been included in the performance evaluation and assessment methods of the policy system. Thirdly, China's anticipation of carbon trading is not deep, and the analysis and sensitivity analysis of carbon trading is insufficient. The research on the impact of carbon market on economic development and cost-effectiveness of controlled enterprises is insufficient.Thus,government should accelerate the legislative process of the carbon trading and strengthen the relative supervision and management. It is recommended to speed up the construction of the national carbon trading market.Carbon trading can be advocated to put in practice, which can expand to various industries of China.

It can be seen from that the construction of the carbon audit evaluation index system can make up for the current blank of low-carbon audit evaluation theoretical research and play a guiding role in low-carbon audit evaluation practice. Given the limited research level of the authors, however, the proposed evaluation index system still has some drawbacks, which will be discussed by theoretical researchers in future exploration and improvement.

6.2 Future research directions

Given the differences in selecting indicators of different industries, future scholars can conduct research on different industries, such as paper industry and electroplating industry, which are also industries with highly polluting and high-emission. When the evaluation system is constructed for these industries, we must fully consider the particularity of the industry. The selection of indicators should be representative and the selected indicators must be able to truly reflect the carbon emissions of enterprises or industries. In addition, when analysing the same industry, different companies can be selected for comparison, which has a great effect on testing the applicability of selected indicators. Many indicators in the same industry are universal, but the specificity of some indicators among different enterprises is also extremely obvious. Thus, when the indicator system is created, the indicators should be refined by industry and sub-enterprise, especially in the industry or when there is a considerable difference between enterprises.

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