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Research on environmental performance evaluation of green automobile manufacturing supply chain

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Abstract: *With the aggravation of global warming, China has set the "dual carbon" goal to control the carbon emission of different industries, which makes automobile manufacturers face great pressure of transformation. As an important means to achieve the goal of "double carbon", the environmental performance evaluation of the green supply chain is of great significance to the sustainable development of enterprises. This paper applies the AHP method to construct an evaluation index system to evaluate the environmental performance of the automobile manufacturing supply chain, including the first-level index of environmental performance of green supply chain of automobile manufacturers, as well as the corresponding second-level and third-level indicators. On this basis, the expert scoring method is used to determine the weight of each index, the rationality of the evaluation system is verified by consistency test, and the environmental performance of the green supply chain of automobile manufacturing enterprises under the background of "dual carbon" is evaluated. Finally, based on the research results, the authors conclude several improvement measures and suggestions, which can help improve the environmental performance of enterprises' green supply chain and realize sustainable development under the goal of "dual carbon".*

Keywords: *Green supply chain; Automobile manufacturer; Environmental performance rating indicators; Analytic Hierarchy Process*

1. Introduction

With the increasingly serious global climate change and environmental problems, the "dual carbon" goal has become the focus of common attention of governments and enterprises. In this context, as one of the main sources of global carbon emissions, the green supply chain management of automobile manufacturing enterprises is of great significance in achieving the goal of "dual carbon". Green supply chain management (GSCM) refers to the sustainable development of the supply chain through reducing resource consumption, reducing environmental pollution, improving resource utilization efficiency and other means in the whole process of the supply chain. However, how to effectively evaluate the environmental performance of the green supply chain of automobile manufacturing enterprises is still an urgent problem to be solved.

Analytic Hierarchy Process (AHP) is a combination of qualitative and quantitative multi-criteria decision-making methods, which can effectively deal with the decision-making process of complex problems. This paper will use AHP to evaluate and study the environmental performance of the green supply chain of the automobile manufacturing enterprises and use AHP to make an empirical analysis of the environmental performance of the green supply chain of the automobile manufacturing enterprises.

2. Literature Review

Ghosh et al. (2022) developed an innovative GSCM performance evaluation framework using six parameters, namely, investment in corporate social responsibility, investment in research and development, utilization of renewable energy, total energy consumption, total carbon-di-oxide emissions and total waste generation. It is found that supplier selection and cleaner production can promote the sustainable development of enterprises. According to Boothroyd in Ford Motor Company, although the production cost accounts for about 5% of the total cost of the product, it determines 80% to 90% of the product life. Li and Zhang (2014) explained the current situation of China's automobile industry from three aspects, which are green design, green processing and remanufacturing. They found that while the

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automobile industry creates wealth and provides convenience for people, it also has a great impact on the environment in terms of resource consumption, so green production design is the key. Zhou et al. (2015) built a two-layer three-dimensional concept model of green logistics, and found that it is necessary to minimize the resource consumption and environmental impact of green logistics systems, so that they can carry out logistics operations in the entire product life cycle of manufacturing (logistics, distribution, packaging). Niu & Wang (2024) proposed the idea of building a new carbon-neutral production line to recycle waste and reduce carbon emissions, and further studied the incentive alignment opportunities for all stakeholders, finding that incentivizing manufacturers to build new carbon-neutral production lines can achieve a win-win situation for all parties.

3. Environmental performance evaluation model construction

3.1. Determine the principles of rating indicators

The environmental performance index of green supply chain of automobile manufacturing enterprises is a comprehensive evaluation system, which is used to measure the environmental impact and performance of enterprises in green supply chain management. The following principles must be followed when determining indicators.

(1) Scientific principle: The design of the index system must be based on science, and the selection of evaluation indicators should focus on the important factors that can affect environmental performance. Indicators in the index system should be connected, but also clear boundaries, qualitative and quantitative combination, the connotation of indicators, and calculation methods should be scientific and reasonable, and strive to be comprehensive.

(2) Operability principle: The operability of an evaluation index system is reflected in the feasibility of action and the practicability of value orientation. The former is the observability and measurability of evaluation indicators. The latter is the guidance of the evaluation index system to improve the environment.

(3) The principle of comprehensiveness: the setting of index items in the system must comprehensively include various factors that may affect the environment. If the evaluation index is not comprehensive, it cannot comprehensively improve or improve the quality of products or services, and thus cannot achieve the strategic goal of improving the environmental benefits of enterprises.

3.2. Selection of rating indicators

According to the ideas and principles of green supply chain environmental performance evaluation system construction, as well as the connotation and essential requirements of green supply chain environmental performance evaluation, the green supply chain environmental performance evaluation index system of automobile manufacturing enterprises was refined into four evaluation indicators under green procurement, green production, green logistics and green recycling, including 4 secondary indicators and 12 tertiary indicators, as shown in Table 1.

(1) Green procurement stage

In the green procurement stage, a total of 3 three-level indicators are set, respectively, green raw materials, supplier selection and enterprise production demand. The Green Raw Materials Index is designed to judge whether the raw materials purchased meet environmental standards. Supplier selection index refers to the selection of long-term partners by enterprises according to their own needs. The production demand index of enterprises mainly considers the quantity, quality and efficiency of purchased goods.

(2) Green production stage

In the green production stage, a total of three levels of indicators are set, namely energy consumption, green production technology and emission control. The energy consumption index focuses on the energy consumption per unit of product, focusing on the efficiency of energy use. The production technical index aims to achieve clean production by improving the production process. The emission control index mainly considers the efficiency of waste gas and wastewater treatment facilities and the discharge standard achievement rate.

(3) Green logistics stage

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In the green logistics stage, a total of three levels of indicators are set, namely transport efficiency, low-carbon transport and green packaging. Transportation efficiency index refers to the optimization degree and transportation efficiency of logistics network. The carbon transport index mainly considers the use of carbon transport modes. The green packaging index focuses on the environmental protection and recycling of packaging materials.

(4) Green recycling stage

In the green recycling stage, a total of three levels of indicators are set, respectively, parts recovery, recycling after material recycling and waste treatment. Parts recovery index refers to the disassembly, classification, processing, remanufacturing and other processes of used auto parts to make them usable parts again. The recycling index after material recycling refers to the treatment and transformation of waste materials or waste products to produce new useful materials or products and realize the recycling of resources. The waste treatment index aims to reduce the amount of waste, reduce environmental pollution and save resources through the classification, recycling and utilization of waste.

Table 1: Environmental performance index system of green supply chain of automobile manufacturing enterprises

Primary index	Secondary index	Three-level index	Reference
Environmental performance of green supply chain in automobile manufacturing enterprises	Green procurement	Green raw material	Zhang & Ye (2016)[6]
		Supplier selection	Zhang & Zhang (2024)[7]
		Enterprise production demand	Hong & Guo (2019)[1]
		Energy consumption Energy consumption	Zhang & Ye (2016)[6]
	Green production	Green production technology	Rao (2002)[3]
		Emission control	Rao (2002)[3]
		Transportation efficiency	Luo (2023)[2]
	Green logistics	Low-carbon transport	Rao (2002)[3]
		Green packaging	Hong & Guo (2019)[1]
		Parts recovery	Rao (2002)[3]
	Green recycling	Materials are recycled	Ritter et al. (2015)[4]
		Waste disposal	Ritter et al. (2015)[4]

4. Determine the indicator weight

According to the constructed environmental performance index system of the green supply chain of automobile manufacturing enterprises, the environmental performance of the green supply chain of automobile manufacturing enterprises is taken as the target layer, and the second and third indexes are set as the criterion layer and the scheme layer respectively to form a hierarchical structure. Scholars from the supply chain field were invited to form an expert group, and the importance of indicators was scored using the nine-place scale method through the judgment matrix of each level. All scoring results were summarized and processed in a geometric average way to obtain the sub-weights of each level of evaluation indicators on the previous layer and the total weights of the target layer (please refer to Table 2-Table 6), and the results were tested for consistency. To determine the calculation formula of matrix Consistency Index CI (Consistency Index, CI), the specific formula is as follows:

$$CI=\frac{\lambda_{max}-n}{n-1} \tag{1}$$

Formula (1) represents the maximum eigenvalue of the judgment matrix, and n is the dimension of the judgment matrix. The closer the value of CI is to 0, the better the consistency between the judgment results. To ensure that all judgment matrices are consistent in general, this paper introduces the random consistency index RI to modify the value of CI. The value of RI is referred to Xu Shubai's Practical Decision Method: Principle of Analytic Hierarchy Process[5] , and the revised random consistency ratio CR is calculated according to the value of RI. The formula is as follows:

$$CR=\frac{CI}{RI} \tag{2}$$

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When CR<0.1, it is considered that there is no obvious conflict between the judgment results and it is acceptable, otherwise it is necessary to readjust the judgment results.

4.1. Weight of each dimension on the target layer

As can be seen from Table 2, under the environmental performance index system of the green supply chain of automobile manufacturing enterprises, the importance of influencing environmental performance is green production (0.519), green procurement (0.201), green logistics (0.201) and green recycling (0.079).

Table 2: Weight of each dimension to the target layer

Target layer	Criterion layer	Weight/total weight
Environmental Performance of Green Supply Chain in Automobile Manufacturing Enterprises	Green Procurement	0.201
	Green production	0.519
	Green Logistics	0.201
	Green recycling	0.079
λ_{max}=4.043,CI=0.014,RI=0.882,CR=0.016		

The calculation result shows that =4.034. According to the RI table, the corresponding RI value is 0.882 and CR=0.016<0.1, which passes the one-time test.

4.2. Internal weight of each dimension

4.2.1. Green Procurement Dimensions

As shown in Table 3, in the dimension of green procurement, the importance of production demand (0.480) and supplier selection (0.406) is relatively balanced, followed by green raw materials (0.115).

Table 3: Weight of each layer of green procurement dimension

Criteria layer	scheme layer	sub weight	total weight
Green procurement	Green raw materials	0.115	0.023
	Supplier selection	0.406	0.082
	Enterprise production demand	0.480	0.096
λ_{max}=3.029,CI=0.015,RI=0.525,CR=0.028			

The calculation result shows that the value is 3.029. According to the RI table, the corresponding RI value is 0.525 and CR=0.028<0.1, which passes the one-time test.

4.2.2. Green Production Dimensions

Based on Table 4, in the dimension of green production, the importance of energy consumption (0.633) ranks first, significantly higher than that of green production technology (0.106) and emission control (0.261).

Table 4: Weight of each layer of green production dimension

Criteria layer	scheme layer	sub weight	total weight
Green production	energy consumption	0.633	0.329
	Green production technology	0.106	0.055
	emission control	0.261	0.135
λ_{max}=3.039,CI=0.019,RI=0.525,CR=0.037			

The calculation result shows that the value is 3.039. According to the RI table, the corresponding RI value is 0.525 and CR=0.037<0.1, which passes the one-time test.

4.2.3. Dimensions of green logistics

As shown in Table 5, in the dimension of green logistics, the importance of transportation efficiency (0.724) ranks first. It can be seen that the improvement of transportation efficiency is significantly more important to the sustainable development of the logistics industry than that of low-carbon transportation (0.193) and green packaging (0.083).

The calculation result shows that the value is 3.065. According to the RI table, the corresponding RI

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value is 0.525 and CR=0.062<0.1, which passes the one-time test.

Table 5: Weight of each layer of green logistics dimension

Criteria layer	scheme layer	sub weight	total weight
Green logistics	Transportation efficiency	0.724	0.145
	Low carbon transportation	0.193	0.039
	Green packaging	0.083	0.016
λ_{max}=3.065,CI=0.032,RI=0.525,CR=0.062			

4.2.4. Green Reclamation Dimensions

Base on Table 6, in the dimension of green recycling, waste treatment (0.633) has the highest importance, which is significantly higher than parts recycling (0.261) and recycling after material recycling (0.106).

Table 6: Weight of each layer in the green reclaim dimension

Criteria layer	scheme layer	sub weight	total weight
Green recycling	Component recycling	0.261	0.021
	Recycling of materials after recycling	0.106	0.008
	Waste disposal	0.633	0.050
λ_{max}=3.039,CI=0.019,RI=0.525,CR=0.037			

The calculation result shows that the value is 3.039. According to the RI table, the corresponding RI value is 0.525 and CR=0.037<0.1, which passes the one-time test.

4.3. Comparison of weight results

According to the subjective views of the experts on the above 16 indicators and the weight of the data calculated, it can be seen that the influence degree of the indicators of the criterion layer on the environmental development of the green supply chain of automobile manufacturing enterprises in the order from largest to smallest is green production (0.519), green procurement and green logistics (0.201), and green recycling (0.079). The index of scheme level has the greatest impact on the environmental development of the green supply chain of automobile manufacturing enterprises: energy consumption (0.329), followed by transportation efficiency (0.145) and emission control (0.135), both of which are above 0.1. Thus, the most critical factor for the environmental performance evaluation of green supply chain in automobile manufacturing industry is green production.

5. Suggestions to the automobile manufacturing supply chain

5.1. Take green production as the core to reduce energy consumption

In the production process, the use of advanced material science and manufacturing technology to produce lighter, stronger, more durable auto parts, should minimize energy consumption and waste emissions; And the use of recyclable, degradable materials to replace traditional plastics and metals; At the same time, artificial intelligence and big data technology are used to optimize the production process, improve production efficiency and reduce costs. It can also further carry out the low-carbon transformation path of green factories, green supply chains and green products in the automotive industry, and guide enterprises to achieve green and low-carbon transformation of production mode through the release of the automobile Green Development Index (GDI). In addition, the development of new energy vehicles also provides new opportunities for automotive companies to develop more efficient and environmentally friendly electric vehicle batteries to meet consumer demand for green travel.

5.2. Strengthen environmental protection and sustainable procurement to reduce operating costs

Environmentally sustainable procurement refers to the preferential selection of products and services that have less impact on the environment, consume less resources, can be recycled and are easy to handle in the procurement process. Enterprises attach importance to supply chain relationship management, fully consider the environmental protection and social responsibility performance of suppliers, and give priority to the selection of suppliers with good environmental protection records and sustainable

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development capabilities; Enterprises Strengthen communication and collaboration with suppliers, logistics providers and other partners to improve the integration of the supply chain. By influencing transaction costs, recovery efficiency, inventory turnover, logistics and transportation efficiency, green supply chain innovation can improve the daily operation efficiency of enterprises, speed up inventory turnover, promote cash recovery, and reduce operating costs.

5.3. Promote the development of green logistics and enhance the competitiveness of transportation

Enterprises through the optimizing the logistics system, scientific and reasonable logistics network design, reduce the transportation distance and time, reduce the traveling distance and time, and reduce energy consumption and emissions by choosing the shortest, fastest and most economical transportation route; It can also work with governments to promote the development and implementation of green logistics policies and standards. It can help automobile manufacturers better understand the latest trends and development direction of green logistics, and take more effective measures to promote the development of green logistics.

5.4. Promote environmental recycling of products and improve resource utilization efficiency

Green recycling of scrapped auto parts conforms to the requirements of circular economy development and meets the current concept of green development, which can not only improve the competitiveness of enterprises, but also be an effective way to create profits. Enterprises promote the scale, standardization and high-value utilization of scrapped vehicle dismantling products, consider the return rate fully, recover rate and reuse rate of parts or vehicles, and constantly improve product performance. When spare parts cannot be used in the original car, they can be used or converted into other vehicles with lower requirements to play their use value. It is also possible to use the technology and equipment of spare parts production plants and automobile manufacturers combined with cascade utilization to make full use of recycled materials and reduce the production cost of new cars.

6. Conclusion

Through in-depth research on the environmental performance of green supply chain of automobile manufacturing enterprises, this paper can better understand the efforts and achievements of enterprises in achieving low-carbon and environmental protection goals. Furthermore, relevant literature was collected and sorted out. From the perspective of coordinated development of green supply chain, a relatively complete environmental performance evaluation system for green supply chain of automobile manufacturing enterprises was constructed. Measures such as focusing on green production, emphasizing supply chain relationship management, strengthening environmental protection and sustainable procurement, optimizing logistics network, and promoting product environmental recycling were further proposed. We hope to provide new ideas for the development of green supply chain of automobile manufacturing enterprises.

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