

# Green Supply Chain Performance Indicators Based on Ecosystem Theory

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**Abstract:** *The green supply chain is in a complex ecosystem. The complexity of interaction increases the diversity and complexity of its performance indicators. Based on the ecosystem theory, this paper analyzes from five aspects including strategy, capability, elements, green and knowledge, and constructs the comprehensive performance index system of green supply chain, which provides a new way to improve the performance of green supply chain management.*

**Keywords:** Ecosystem; Green supply chain; Performance indicators

## 1. Introduction

With the development of economic globalization, the dynamic uncertainty in economic operation has been increasingly intensified, and market competition has been developing in a complicated direction, presenting many new features: With the rapid expansion of product varieties, the product life cycle becomes shorter and shorter. Users have higher and higher expectations for delivery time, products and services, and resource utilization and environmental issues are getting more and more attention. Enterprises must cooperate with upstream and downstream enterprises, establish an industry alliance with economic interests linked, resources and environment related, and close business relations, make full use of all available resources to adapt to the competitive environment of large-scale socialized production, and enhance market competitiveness. Ecosystem is a new growth mechanism which can effectively simulate the evolution of multiple enterprises and their interrelated environments. From the perspective of ecosystem, it is very necessary to explain the mutual influence and interaction between enterprises for the in-depth study of green supply chain. The successful operation of a green supply chain requires close attention and understanding of the environment and the organizations that influence its evolution. By constantly creating, accumulating and utilizing knowledge resources, it makes rapid collaborative response to environmental changes and market demands, and achieves a high integration of interaction modes and results among cooperative enterprises in the ecosystem.

Green supply chain performance indicators evaluation is the key component of green supply chain management. On the one hand, it can reflect the competitive advantages and capabilities of the green supply chain in an all-round and multi-angle way, and find out the deficiencies of its performance to improve. On the other hand, the reference system of effective financing mechanism can be established. Therefore, it is of great significance for the implementation, development and specific application of green supply chain management to conduct systematic and in-depth research on it. At present, there are many researches and literatures on the index system of supply chain performance evaluation. Ma et

al. proposed evaluation indexes that can reflect the performance of the entire supply chain business process, including: production-sales ratio index, average production-sales absolute deviation index, production-demand ratio index, supply chain product production cycle index, supply chain overall operating cost index, supply chain core product index and supply chain product quality index [1]. Fang et al. put forward an evaluation system based on customer satisfaction, and carried out quantitative analysis by using analytic hierarchy process (AHP) [2]. Xu proposed an integrated framework for the evaluation of supply chain performance, which was evaluated from the two dimensions of customer value and supply chain value. Customer value can be described by flexibility, reliability, price and quality, while supply chain value can be described by supply chain input, output and financial evaluation [3]. Wang et al. analyzed the agile supply chain, and then proposed to construct the supply chain performance evaluation index system from four aspects: customer satisfaction, flexibility, information sharing and cost [4]. Zhang et al. discussed the performance evaluation index system of green supply chain management from three aspects: core enterprise performance level, supply chain management level and supply chain green level [5].

The above evaluation indexes are all constructed from some or several perspectives or even from the whole of supply chain performance evaluation, and their performance evaluation perspectives and focuses are different. From the perspective of business system theory, this paper mainly analyzes the performance evaluation of green supply chain and constructs the index system to improve the current evaluation index system. By applying the ecosystem theory to the study of green supply chain, the paper focuses on the macro-systematic thinking of the ecosystem of green supply chain, and opens up a new way to understand the green supply chain from a new perspective.

## 2. Literature review

### 2.1 Ecosystem theory

Ecosystem theory is an important theory in biology to study

the competition among organisms, the adaptability of organisms to environment, the diversity and stability of ecosystem. American management scientist James f. Moore put forward the theory of business ecology for the first time in his book "the decline and death of competition", and preliminarily established the theoretical framework of business ecosystem by using ecological principles [6]. Zhao analyzes the general characteristics of business system, compares business system with network organization, value network, dynamic alliance, network organization and other concepts, and points out the competitive advantages of business ecosystem [7]. Liu studies the relationship between supply chain management and business ecosystem, and points out that the purpose of supply chain management is to ensure the maximum value of business ecosystem and the healthy development of the system [8]. Therefore, from the perspective of ecosystem theory, green supply chain can be regarded as composed of many ecologically dependent organizations, each of which contributes to the green and sustainable operation of the whole chain or network. Therefore, in order to achieve a stable green supply chain with sustainable development, it is not only necessary for all organizations to achieve a thorough ecological system theory embedding, but also requires the deep integration of green supply chain and macro ecological environment.

## 2.2 Green supply chain theory

The national science foundation funded an "environmentally responsible manufacturing" study by the manufacturing research association at Michigan state university, the project group proposed the concept of green supply chain in 1996. Steve V Walton et al. believe that green supply chain management is to add suppliers to the enterprise's environmental strategy, and its core is to apply the idea of integrated management to the field of green supply chain [9]. M.H.Nagel believes that green supply chain management involves the whole process of product use, composition and production [10]. According to Dan, green supply chain is a modern management mode that comprehensively considers environmental impact and resource efficiency in the whole supply chain. It is based on green manufacturing theory and supply chain management technology, involving suppliers, manufacturers, sellers and users. The purpose is to minimize the environmental impact (negative impact) and maximize resource efficiency in the whole process from material acquisition, processing, packaging, storage, transportation, use to scrap disposal. The basic goal of green supply chain management is environmental protection and optimal utilization of resources [11]. On the basis of previous studies, Wang et al. systematically subdivided the green supply chain into production subsystem, consumption subsystem, social subsystem and environmental subsystem. Its constituent elements include suppliers, manufacturers, distributors, consumers and recyclers. The objectives of green supply chain operation are defined as "environmental friendliness, welfare enhancement and optimal allocation of resources" [12].

## 2.3 Coupling of green supply chain and ecosystem theory

In ecology, ecosystem refers to a relatively stable dynamic equilibrium system formed by the interaction, influence and evolution between organisms and environment within a certain time and space. According to the definition of green supply chain, it has typical ecosystem characteristics.

From the perspective of green supply chain, green supply chain management pays attention to the coordinated development of each member of the supply chain, each link and the environment, and pays attention to the integrity of the whole supply chain system. At the same time, the development of the supply chain from the traditional single chain vertical integration to horizontal integration and vertical integration of the trend of the development of the common, more and more tend to network, from the static to the dynamic process of a species in ecosystems exist between the intricacies of the community and network relations, in the development of dynamic coevolution [13]. This provides another good interface for the coupling between green supply chain management and ecosystem theory.

From the point of view of ecosystem, ecosystem theory is an important theory to study the competition between organisms, the adaptability of organisms to environment, the diversity and stability of ecosystem [14]. The ecological niche of an enterprise is the characteristics of the enterprise in terms of resource demand and production capacity. A single enterprise should have its own ecological niche, and enterprise population is a collection of enterprises with similar ecological niche [15]. At the same time, an enterprise's ecological niche is an objective relationship positioning based on the interaction between environmental resources and the inherent nature of the enterprise. It is an objective state after the interaction between the enterprise and the environment matches, expressing a coexistence equilibrium state formed between the enterprise and the environment [16]. Therefore, from the perspective of ecosystem, green supply chain can be regarded as composed of many ecologically dependent organizations, each of which contributes to the green and sustainable operation of the whole chain or network [17]. The existence of ecosystem theory is also adding variables to the changes of green supply chain management.

Based on the ecosystem theory, five enterprise niche dimensions are embedded into the green supply chain, including strategy, capability, elements, knowledge and green. Strategy refers to the development direction and trend of the enterprise in the future. Capacity refers to the viability, development and competitiveness of an enterprise formed by optimizing its internal structure and integrating its management level within the framework of production capacity, sales capacity and service capacity. Elements refer to the product, technology and operating basis of an enterprise and its specific position, including products, technologies and various activities supporting the operation of the enterprise. These factors determine its position in the ecological niche. Green is the degree to which an ecosystem is green or

environmentally friendly. Green supply chain should reduce the consumption of natural resources, reduce the impact of production and trading on the environment, and on the basis of achieving the basic management objectives of the supply chain, highlight the green nature of the supply chain, and coordinate various environmental information. Knowledge is the process of enterprise knowledge learning, knowledge utilization and knowledge creation. According to the evolutionary logic of organizational ecology, through organizational learning, the application and creation mechanism of knowledge can be formed, and then through self-organization, the core competence and infrastructure of organizational evolution can be developed, so that the organization has the life characteristics of biological organism, such as the ability to respond to complex environment sensitively. Knowledge learning and application ability, knowledge transformation and innovation ability can effectively enhance the market competitiveness of the supply chain, so as to maintain its sustainable survival and development. It is the final effect of the first four dimensions, and will also determine the development and change of the other four dimensions for a long time.

### 3. Construction of green supply chain performance evaluation index system based on ecosystem theory

This paper analyzes the related problems in the process of green supply chain management by combining five different enterprise niche dimensions, establishes the theoretical index system of green supply chain ecosystem, and provides the theoretical basis for effectively solving the practical problems in the process of green supply chain management.

#### 3.1 Strategy

Strategy refers to the development direction and trend of an enterprise in the future. It is the overall and guiding planning of setting long-term goals and the trajectory of achieving the goals. It is influenced by vision planning, external environment and internal factors. Therefore, the embedding of ecosystem theory in this dimension will more effectively promote the embedding of other dimensions in ecosystem theory. The ecosystem embedding in the strategic dimension is mainly reflected in the enterprise strategic planning. This paper takes the strategic dimension as the first second-level indicator of the green supply chain performance indicator system, and evaluates it from three perspectives: strategic matching degree, capital value and customer satisfaction

#### 3.2 Capability

The production, sales, service and other capabilities of enterprises determine the survival and development of enterprises, and the embedding of the ecological system theory in this ecological niche dimension also determines the performance and results of enterprises in the green supply chain. The fundamental goal of the implementation of green supply chain is through the core enterprise and suppliers, distributors and other related node enterprises in close cooperation and information sharing, to further improve

product quality, reduce production cost, shorten the product output cycle time and enhance supply chain reaction speed and flexibility, improve responsiveness to meet customer demand, finally enhance the market competitiveness of the whole supply chain [18]. Therefore, this paper evaluates the performance of green supply chain from the capability dimension, and further evaluates the indicators from the seven perspectives of development capacity, reliable delivery capacity, production and marketing capacity, production and demand capacity, service capacity, capital operation capacity and nodal enterprise relationship capacity.

#### 3.3 Elements

Elements include products, technologies, and activities that support business operations. From the perspective of the embedding of the green supply chain ecosystem theory, the embedding of the ecosystem theory of the factor dimension should focus on product quality, supply chain response flexibility and a series of activities supporting supply chain operation. This is one of the driving forces for the development of green supply chain. Thus, factor dimensions are divided into five indexes: flexibility, quality, transportation, warehousing and information.

#### 3.4 Knowledge

Knowledge is the process of enterprise knowledge learning, knowledge utilization and knowledge creation. Eco-type enterprises have the ability of rapid self-learning and a certain degree of wisdom. They can develop different survival abilities, skills and strategies through self-organization, have the sensitive response ability to complex environmental changes, and realize co-evolution or variation with the environment, so as to maintain the vitality of their sustainable survival and development. The embedding of ecosystem theory in the knowledge dimension mainly focuses on the learning ability and innovation ability of enterprises in the ecosystem, which can effectively enhance the market competitiveness of the supply chain, so as to maintain its sustainable survival and development. This dimension is mainly evaluated from the perspectives of learning innovation and patent application.

#### 3.5 Green

Green can be defined as the degree of green in the ecosystem or the degree of environmental friendliness, that is, the degree of environmental impact is quantified. The evaluation of green level of green supply chain will inevitably bring corresponding influence to other traditional evaluation indexes. With the enhancement of people's "green consciousness", indicators such as customer satisfaction and market share are inevitably affected by this awareness in the performance level assessment of core enterprises. In the cost evaluation of green supply chain, the cost composition of traditional supply chain, product recycling and treatment, selection and use of harmless materials, negative impact on the environment and cost of environmental treatment should be included in the cost assessment. And the expansion of cost scope will inevitably further affect the benefit of the entire supply chain. Meanwhile, due to the influence of "green

consciousness", the development of new products and product quality assessment will be affected by "green". The embedding of ecosystem theory in the green dimension will also further affect the embedding of other dimensions in the ecosystem theory, which is mainly measured from the four perspectives of environment, resources, energy and

recyclability.

Combining the five different structural dimensions mentioned above, a green supply chain performance indicators system based on ecosystem theory is further constructed, as shown in Table 1.

**Table 1:** Green supply chain performance indicator system based on ecosystem theory

First class index	Second class index	Third class index	
Strategy X <sub>1</sub>	Strategic matching degree X <sub>11</sub>	Strategic matching degree of member enterprises X <sub>111</sub>	
		Strategic matching degree of other functions X <sub>112</sub>	
	Capital value X <sub>12</sub>	Rate of return on total assets X <sub>121</sub>	
		Economic value appreciation X <sub>122</sub>	
		Return on equity X <sub>123</sub>	
	Customer satisfaction X <sub>13</sub>	Regular customer retention rate X <sub>131</sub>	
		New customer growth rate X <sub>132</sub>	
	Capability X <sub>2</sub>	Development capacity X <sub>21</sub>	Sales revenue growth rate X <sub>211</sub>
			Profit growth rate X <sub>212</sub>
Reliable delivery X <sub>22</sub>		Stockout rate X <sub>221</sub>	
		Supply ratio X <sub>222</sub>	
		On-time delivery rate X <sub>223</sub>	
Production and marketing X <sub>23</sub>		Supply chain production and sales ratio X <sub>231</sub>	
Production needs X <sub>24</sub>		Supply chain production demand ratio X <sub>241</sub>	
Service X <sub>25</sub>		Customer complaint rate X <sub>251</sub>	
		Customer complaint resolution time X <sub>252</sub>	
Capital operation X <sub>26</sub>		Total asset turnover X <sub>261</sub>	
		Inventory turnover X <sub>262</sub>	
		Cash turnover X <sub>263</sub>	
Nodal enterprise relationship X <sub>27</sub>		Node average delivery time X <sub>271</sub>	
		Timeliness of information transmission X <sub>272</sub>	
		After-sales service quality X <sub>273</sub>	
	Nodal enterprise loyalty X <sub>274</sub>		
Elements X <sub>3</sub>	Flexible X <sub>31</sub>	Flexible product X <sub>311</sub>	
		Quantitative flexibility X <sub>312</sub>	
		Flexible time X <sub>313</sub>	
	Quality X <sub>32</sub>	Product qualification rate X <sub>321</sub>	
		Rejection rate X <sub>322</sub>	
		Product warranty return rate	

		$X_{323}$
	Transport $X_{33}$	On-time rate $X_{331}$
		Transportation accuracy $X_{332}$
		Transport loss rate $X_{333}$
		Warehouse utilization $X_{341}$
	Warehousing $X_{34}$	Inventory turnover $X_{342}$
		Cargo defect rate $X_{343}$
		Inventory accuracy $X_{344}$
		Information timeliness $X_{351}$
	Information activities $X_{35}$	Information accuracy $X_{352}$
Knowledge $X_4$	Learning innovation $X_{41}$	Growth rate of training hours $X_{411}$
		New product development investment rate $X_{412}$
	Patent $X_{42}$	Patent growth rate $X_{421}$
Green $X_5$	Environment $X_{51}$	The environmental pollution $X_{511}$
		Environmental treatment cost $X_{512}$
	Resources $X_{52}$	Material utilization $X_{521}$
		Equipment utilization $X_{522}$
		Use ratio of harmless materials $X_{523}$
	Energy $X_{53}$	Energy efficiency $X_{531}$
		Product energy consumption $X_{532}$
	Recyclability $X_{54}$	Product recovery $X_{541}$

4. Evaluation model

$$X_{54} = \{ X_{542} \}$$

4.1 Establish evaluation index set

The performance evaluation index system of green supply chain includes first class index, second class index and third class index. Set the first class index set of the green supply chain performance evaluation system as  $X = \{X: X_1, X_2, X_3, X_4, X_5\}$ . Each of the first class index  $X_i$  ( $i=1, 2, 3, 4, 5$ ) has  $G_i$  second class index,  $X_i = \{X_i: X_{i1}, X_{i2}, X_{Gi}\}$  ( $i=1, 2, 3, 4, 5$ ). The second class index set is as follows:

- $X_1 = \{X_{11}, X_{12}, X_{13}\}$
- $X_2 = \{X_{21}, X_{22}, X_{23}, X_{24}, X_{25}, X_{26}, X_{27}\}$
- $X_3 = \{X_{31}, X_{32}, X_{33}, X_{34}, X_{35}\}$
- $X_4 = \{X_{41}, X_{42}\}$
- $X_5 = \{X_{51}, X_{52}, X_{53}\}$

Similarly, the third class index set can be obtained as follows:

- $X_{11} = \{X_{111}, X_{112}\}$
- $X_{12} = \{X_{121}, X_{122}, X_{123}\}$
- .....
- .....

4.2 Establish the weight coefficient matrix

Let the weight of  $X$  be  $W$  ( $I = 1, 2, 3, 4, 5$ ). Then, the first-order weight set is:  $W = \{W_1, W_2, W_3, W_4, W_5\}$ , ( $0 < W < 1$ ). Let the weight coefficient of second class index  $X_{ij}$  be  $W_{ij} = \{W_{ij} | i = 1, 2, 3, 4, 5; j = 1, 2, \dots, G_i\}$ . Thus it follows:

- $W_1 = \{W_{11}, W_{12}, W_{13}\}$
- $W_2 = \{W_{21}, W_{22}, W_{23}, W_{24}, W_{25}, W_{26}, W_{27}\}$
- $W_3 = \{W_{31}, W_{32}, W_{33}, W_{34}, W_{35}\}$
- $W_4 = \{W_{41}, W_{42}\}$
- $W_5 = \{W_{51}, W_{52}, W_{53}\}$

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- .....
- $W_{54} = \{W_{541}\}$

Weight distribution adopts the weight factor judgment method, which is a weight determination method that quantifies the qualitative evaluation. Compared with AHP and other methods, it is simple and easy to operate. In this paper, the comparative judgment matrix is constructed by multiple experts, and then the comprehensive evaluation results are given. The specific operation process is as follows:

Firstly, 20 people are selected from supply chain scholars and related enterprise management experts to form the evaluation expert group. Secondly, make the evaluation index factor judgment table. Then, experts are invited to evaluate and fill in the weight factor judgment form. The row and column factors are compared and scored according to their relative importance. Using a 5-point system, very important index is 5 points, compared with more important index is 4 points, equally important index is 3 points, compared with less important index is 2 points, compared with very unimportant index is 1 point. Finally, statistical analysis is carried out according to the scores of experts.

(1) Calculate the score of each line of evaluation indicators:

$$H_{in} = \sum_{i=1}^{G_i} y_{ij} \quad (1)$$

Where, n represents the serial number of experts, and  $G_i$  represents the number of evaluation indicators of this level,  $y_{ij}$  is the index score value of the evaluation index I compared with the evaluation index j.

(2) Find the average score of the evaluation indicators:

$$V_i = \sum_{n=1}^N H_{in} / N \quad (2)$$

Where N is the total number of experts.

(3) Calculate the weight value of the evaluation index:

$$W_i = V_i / \sum_{i=1}^{G_i} V_i \quad (3)$$

#### 4.3 Calculation of quantitative indicators

When the quantitative index is implemented, the evaluation subject can collect or calculate the index score from the enterprise financial report and the enterprise internal management data and other information sources. The evaluation and scoring of quantitative indicators can be dimensionless by using the linear interpolation continuous scoring model and converted to a percentage system. Specific operations are as follows:

When the index is positive, the upper limit effect measure is adopted, and the calculation formula is:

$$Y_i = u + \frac{P_i - P_{min}}{P_{max} - P_{min}} \times (v - u) \quad (4)$$

When the index is negative, the lower limit effect measure is adopted, and the calculation formula is:

$$Y_i = u + \frac{P_{max} - P_i}{P_{max} - P_{min}} \times (v - u) \quad (5)$$

Where,  $Y_i$  is an evaluation index;  $P_i$  is the original data corresponding to the statistical indicators of the enterprise;  $P_{max}$  is the maximum value of the enterprise in the evaluation standard of this index;  $P_{min}$  is the minimum value of the enterprise in the evaluation standard of this index; u is the

lower limit of the score of this index, where  $u=60$ ; v is the upper limit of the score of this index, where  $v=100$ .

#### 4.4 Scores of qualitative indicators

For qualitative indicators, the method of comments can be used to divide each qualitative indicator into five grades: A (excellent), B (good), C (medium), D (general) and E (very poor), and then set the scores of each registration as 100, 80, 60, 40 and 20. Through the Delphi method, the index scores of each layer are calculated by experts on the basis of comprehensive expert scores. The calculation formula is:  $Y_i = 100f_a + 80f_b + 60f_c + 40f_d + 20f_e$

f = the number of experts on a comment/the total number of experts

#### 4.5 Comprehensive evaluation score

According to the evaluation criteria of each indicator and the weight table of factors and indicators, the quantitative evaluation of each evaluation indicator is carried out, and then the comprehensive performance evaluation index of the green supply chain is obtained by weighted synthesis of the weighted value of each evaluation indicator.

Comprehensive performance of green supply chain  
 $= \sum Y_i \times W_i$

### 5. Conclusion

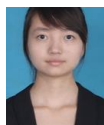
The green supply chain is in a complex ecosystem. The ecological system theory is embedded into the green supply chain management process and permeates into each operation module, which has a certain impact on the operation performance of enterprises. Meanwhile, with the enhancement of environmental protection and ecological consciousness of upstream and downstream members of the supply chain, the transformation and upgrading process of green ecological manufacturing has been promoted. The introduction of ecological system theory is helpful to further improve the overall performance level of the green supply chain. Therefore, this article embarks from the ecology evolution of ecosystem, combining with the characteristics of green supply chain, respectively from the strategy, green, and the knowledge, ability, elements were analyzed, and constructs the comprehensive performance index system of green supply chain, enrich the theory of performance evaluation of knowledge, to enhance the performance of green supply chain management provides a new way.

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