Economics

# Sustainable development of low-carbon supply chain economy based on the Internet of Things and environmental responsibility

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# Sustainable development of low-carbon supply chain economy based on the Internet of Things and environmental responsibility.

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**Abstract:** This article examines and analyzes the development of a low-carbon supply chain from the two aspects of the Internet of Things and environmental responsibility to better support the sustainable growth of a low-carbon supply chain economy and raise people's standards of living. Research results show that the industrial scale of China's low-carbon supply chain economy is expected to exceed 300 billion by 2025. At present, there are still economic development barriers, but integrating the Internet of Things technology and environmental responsibility consciousness into economic development, it has the potential to strengthen the development of a low-carbon supply chain and improve the conditions for long-term, sustainable growth.

**Keywords:** supply chain, economy, Internet of Things, economic development, sustainable growth.

## 1Introduction

In recent years, China has been faced with increasingly serious environmental and resource problems. The emissions of industrial pollutants, especially carbon emissions, have exceeded the carrying capacity of resources and environment, resulting in serious air pollution, acid rain and continuous fermentation of smog in many cities. Based on the latest statistics released by China, research group Carbon Brief calculated that China's Carbon emissions totaled 10 billion tons in 2018, up 2.3% from 2017 (when co2 emissions grew 1.7%). In recent years, the complexity of environmental problems and a series of environmental changes have occurred in the process of enterprise industrialization construction in China. Therefore, how to deal with carbon emissions will be an important problem facing society and enterprises. Meanwhile, with the development of supply chain node enterprises, resource consumption and carbon emission of low-carbon supply chain are becoming increasingly serious. These results are closely related to the carbon dioxide reduction, energy efficiency and carbon emission of supply chain node enterprises. Figure 1 depicts the research technology roadmap.

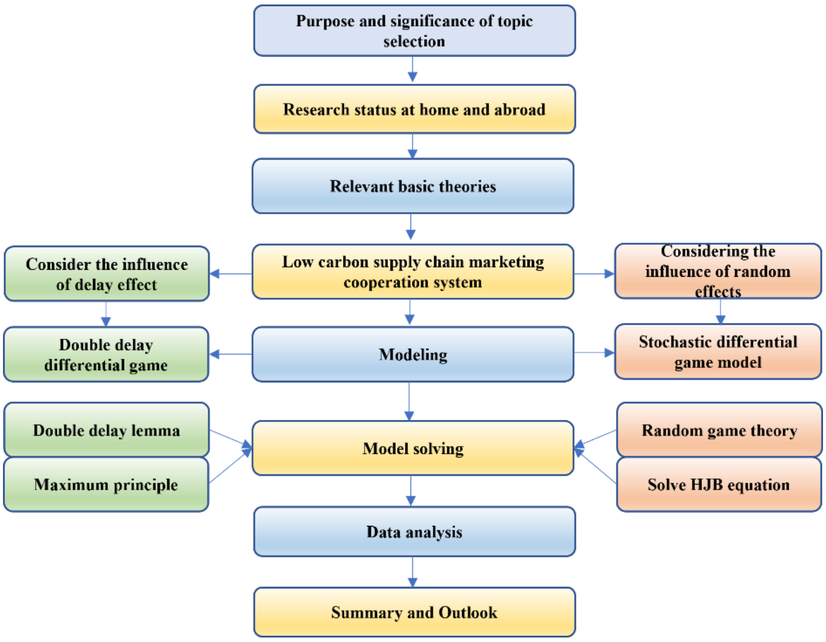



**Figure 1 Technological research roadmap**

As the supply chain's resource and energy usage continue to increase, environmental pollution and ecological destruction, environmental protection, governance and carbon emission reduction will face increasing pressure. Due to different industries, different industries within the industry and within the industry, there will be great differences in the energy demand structure of the supply chain, the pattern of resource allocation, the production process and the resource attributes of the supply chain [1-2]. In recent years, many well-known international manufacturing enterprises have achieved good environmental and social benefits through low-carbon supply chain management. In the industrial low-carbon development Plan (2016-2020), low-carbon manufacturing Engineering Implementation Guide (2016-2020), Made in China 2025, China manufacturing low-carbon supply chain development report the significance of low-carbon supply chain research has also been highlighted in 2018. Therefore, under the above research background, this essay starts from the perspective of resource attributes of low-carbon supply chain and draws lessons from the research results of low-carbon supply chain at home and abroad [3]. From the perspective of flexible resource and environmental attributes, the focus of the research is on flexible resource allocation in low-carbon supply chains, and multi-attribute, granular computing, cloud model, artificial intelligence algorithm, hybrid neural network and other theories and methods are applied. The construction of a flexible resource allocation model in a low-carbon supply chain and the parameters design of flexible resource allocation are the subjects of creative theoretical research, the design of hybrid algorithm based on cloud model and its robustness verification, in order to get useful conclusions to guide the actual operation of low-carbon supply chain in China's manufacturing industry. This article significantly enhances the low-carbon performance of flexible resource allocation in low-carbon supply chain and accomplishes the efficient allocation of flexible resources in low-carbon supply chain from the perspective of resource characteristics [4-5]. The supply chain management structure diagram is shown Figure 2 below.

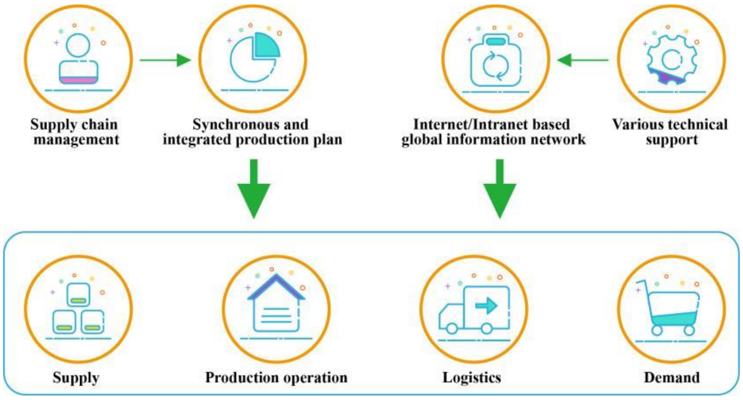



**Figure. 2 Supply chain management structure diagram**

## 2 Literature review

In the early study of flexibility, many scholars believed that flexibility is a measure of the strain capacity of supply chain resources. Mandalbaum points out that flexibility is a kind of executive ability of a supply chain to cope with changing environment, and Gupta points out that supply chain resources have the attribute of multi-mode executive ability, and flexibility is a kind of strain ability to deal with external changes quickly. Tatikonda et al. divided manufacturing flexibility into multiple dimensions including machine flexibility and mixed flexibility to study manufacturing resources[6]. At the same time, they concluded that the higher the flexibility of resources, the stronger its ability to cope with the changes of manufacturing objects. Vickery et al. believe that the concept of supply chain flexible resources is considered from an integrated, customer-oriented perspective, and defines the flexibility of supply chain as output flexibility, new product flexibility, response flexibility and other aspects of the study. Kostas Axarloglou and Ilias Visvikis studied resource flexibility and the method of allocation of flexible resources, and pointed out that production flexibility is determined by the flexibility of allocation of resources and the relationship between resources. Ehap H Sabri and Beamon(present an overall resource flexibility measurement model for supply chain system integration, It provides a more accurate measurement of the chain equipment performing better than the conventional measurement. In addition, the measurement model provides a multi-objective vector performance for all connected equipment, and the simple measurement provides a good way to improve the basic capabilities. Xiang-zhongchu et al. Supply chain flexibility resource clustering trends are highlighted, supply flexibility assessment can identify the need to improve product flexibility and determine the best direction to improve the uniqueness of flexible products. Yim. again. Figure 3 below illustrates a low-carbon material.

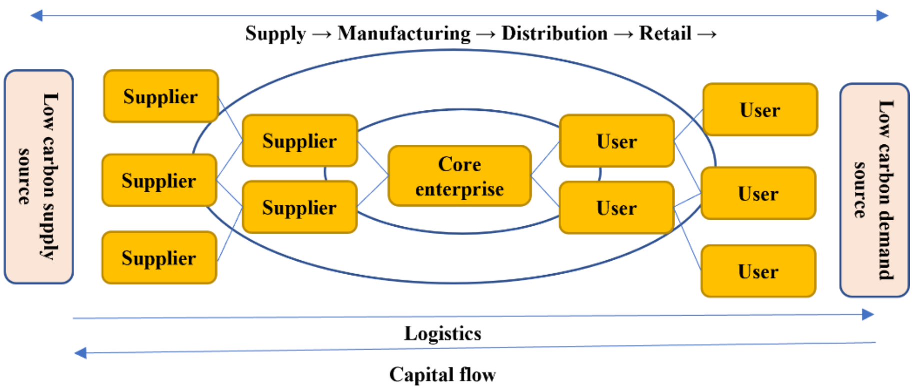


**Figure 3. Model of low-carbon supply chain network structure**

Low-carbon performance is an important embodiment of a low-carbon supply chain. low-carbon performance of companies in the export improvement industry. Therefore, the significance of low carbon content in low carbon chain management must be emphasized. Yang Dong and Chai Huimin presented the results and descriptions of many kinds of low-carbon electric motors after looking into the forces driving low-carbon technology and the effects of low-carbon technology innovation on low-carbon materials. Low carbon performance is greatly influenced by low carbon content, cutting-edge technology, and environmental factors. Some scientists have argued that pollution control has a major impact on the low efficiency of low carbon emissions by industry standards, and the environmental characteristics of capital. layer affects the low efficiency of the business [7]. At the same time, it was pointed out that the direct impact of pollution control of low-carbon materials is greater than the direct effect, and the efficiency of low-carbon can be improved by improving the environmental characteristics of the chain equipment [8]. In Figure 4 below, a platform management device is shown.

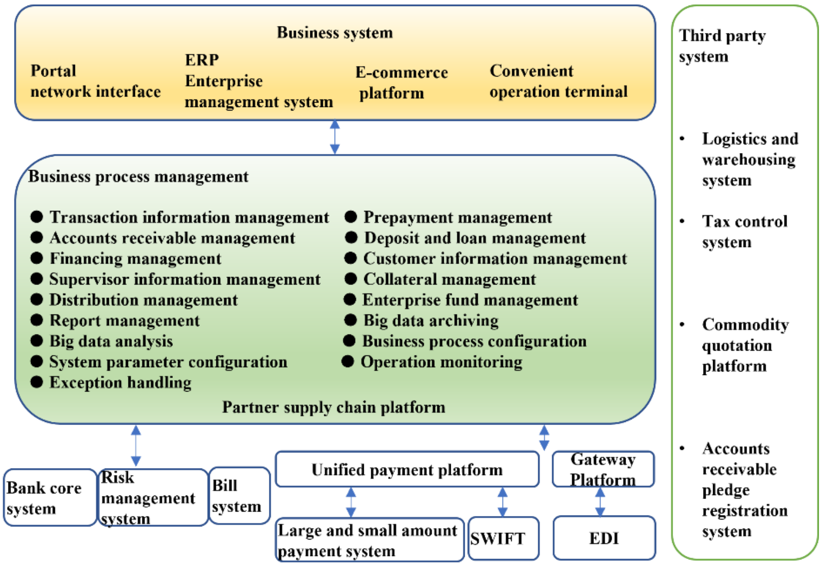



**Figure. 4 Supply chain management platform diagram**

## 3 Sustainable development requirements of low-carbon supply chain economy based on Internet of Things and environmental responsibility

For the sector to have a higher competitive edge, managing low-carbon chains is essential. Given how widely accepted the concept of a low-carbon economy is, people's awareness of environmental protection is increasing day by day, and consumers are choosing more environmentally friendly products. Reducing expenses through green supply chain management is the only option. Expert analysis shows that from production to sales, production and turnaround time is only 10%, nearly 90% is transportation, loading and unloading., sub-packaging, secondary processing, document processing and other logistics processes. Large loads and small equipment are the characteristics of low-carbon supply chain management, thus saving and reducing operating costs, including low carbon, energy saving, high efficiency, and pollution. less, with larger results. production and operation cost savings [9]. In this way, by maintaining the green supply chain, consumers can get better products, and businesses can get long-term business cooperation and improve businesses' competitive advantage. As shown in Figure 5:

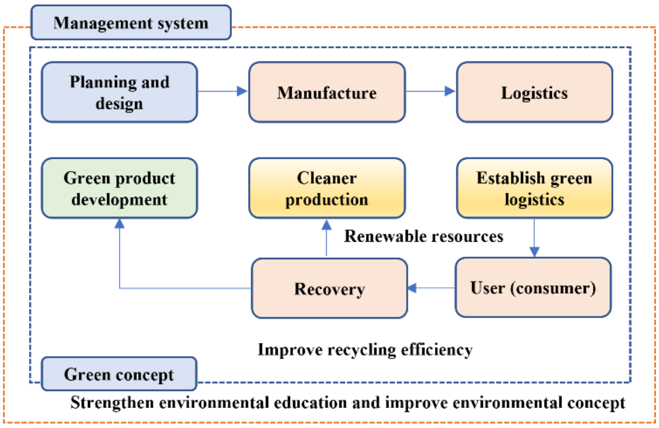



**Figure 5 supply chain management system diagram**

**3.1 Realization of basic algorithm for sustainable development of low-carbon supply chain economy based on Internet of Things and environmental responsibility**

3.1.1Model description

This essay investigates the product marketing cooperation system of low-carbon supply chain, which consists of a single manufacturer (D) and a single retailer (C) under the influence of delay effect [10]. Hypothesis 3-1: Both parties aim to maximize their own benefits, and are completely rational and have complete information. Regarding the promotion of low-carbon products, producers' and retailers' tasks are $E_D$ (t) and $E_C$ (t), $\lambda_D>0$ and $\lambda_C>0$ represent the marketing cost coefficients of manufacturers and retailers, respectively. The actual expressions of marketing costs $C_D$ (t) and $C_C$(t) of both parties are shown in Formula (1) below.

$$C_D(t)=\frac{\lambda D}{2}E_D^2(t);\ C_C(t)==\frac{\lambda c}{2}Ec^2(t)\ (1)$$

Hypothesis 3-2: The more favorable the product's low-carbon reputation is, the more it can improve consumers' purchase intention and trust in the product. Suppose G(t) indicates supply chain goodwill with minimal carbon. In such cases the system's starting condition is G (0) =$G_0$; α and β represent the influence degree of manufacturer's and retailer's efforts in low-carbon product marketing on low-carbon goodwill, namely, marketing effort level coefficient. ds and dz represent the delay time of manufacturer's and retailer's marketing effort strategy Ɛ respectively; Manufacturers' and retailers' low-carbon supply chain marketing initiatives are displayed in Figures 6 and 7 below. δ>0 represents the attenuation coefficient of low-carbon goodwill in low-carbon product marketing system. Based on the N-A model, considering the delay characteristics of marketing efforts in practice, the following delay differential equation is used to explain how product goodwill varies dynamically (2):

$$G(t)=\alpha E_D(t-dz)+\beta E_C(t-ds)-\delta G(t),\ G(0)=G_0\ (2)$$

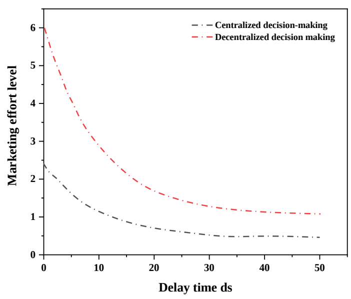


**Figure. 6 Comparison of retailers' marketing efforts and strategies**

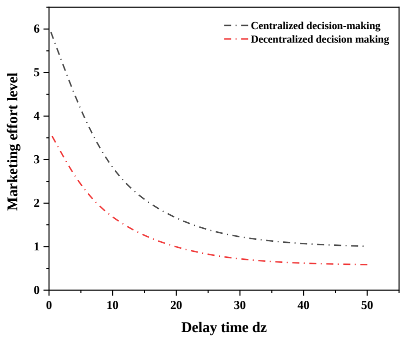



**Figure. 7 Comparison of manufacturers' marketing effort strategies**

Because the delay time exists in three cases: DS is greater than Dz, DS is less than Dz, ds is equal to Dz. If DS is greater than Dz as an example, the G(t) segment is brought into the evolution of low-carbon goodwill. In the whole time range, its interval is [0, DS), [DS, DZ), [DS, ∞). The first time interval is the initial point of G0, and the initial value of the second interval is the right endpoint of the first interval, and so on.As shown in Figure 8 and 9,10:

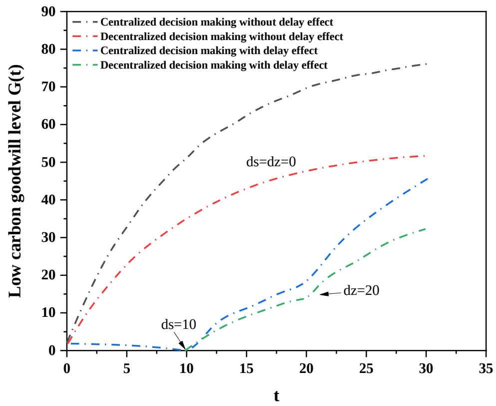



**Figure. 8 Evolution of ds greater than dz low-carbon goodwill**

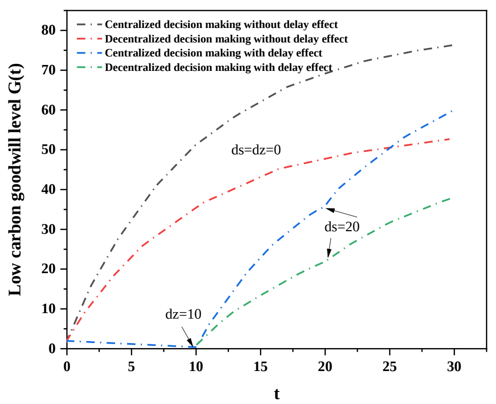



**Figure. 9 Evolution of low carbon goodwill with ds less than dz**

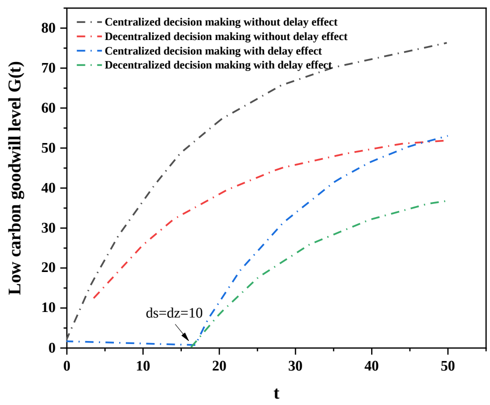



**Figure 10 ds equals dz low-carbon goodwill evolution process diagram**

Hypothesis 3-3: The income obtained from the marketing cooperation system of low-carbon product supply chain is distributed between the two cooperative entities, and the income distribution coefficient is determined for both parties in advance. Where the retailer gets (0,1) and the manufacturer gets 1-. In actual production, in order to encourage retailers to conduct low-carbon product marketing, manufacturers will take the initiative to bear the marketing cost of (t) for retailers. (t)(0,1) represents "subsidy factor"[11]. In the infinite time zone, the goal of both companies is to seek the optimal marketing effort strategy to ensure the maximization of their respective income. And both parties discount their future earnings at a fixed rate of 0. The manufacturer's objective function is formula (3) :

$Y_D=\mu\omega_0 e^{-}\rho^t$[（1-ω）（$\beta E_C$(t)）+γED(t)+€G(t)]dt（3）

**3.2 Delayed effect**

As shown in Equation (4)

E[t，x（t），$u_1$（t），$u_2$（t），um（t）]$d_t$+$Q_i$（x（T））]dW（t），x（t0）(4)

In this formula, E is the mathematical expectation, t, x (t) is the matrix m*θ, dW (t) is the Wiener process of θ, and the initial state is X0.

The delayed effect is included in the study of the marketing cooperation system of low-carbon supply chain, and the case where the delayed effect exists in the marketing effort strategies of both manufacturers and retailers of low-carbon products is also considered. A two-delay differential game model is constructed under dynamic environment, and the evolution process diagram of low-carbon goodwill of products is drawn according to the different relationship between two delay times. The influence of delay effect on system optimal profit and low carbon goodwill is analyzed. The decision basis and the effect of manufacturer's subsidy ratio to retailer's marketing effort under double delay effect are explored. And gives the corresponding management enlightenment [12]. To gather useful information for the low-carbon supply chain marketing cooperation system's participants to use as a foundation for decision-making and to offer accurate theoretical direction for promoting the growth of low-carbon supply chain marketing cooperation.

**3.3 Low carbon supply chain energy saving technology in economic production**

Therefore, first, it seeks to increase investment in science and technology, increase new democratic capabilities, and measure integration, modification, and use of technology. old urine existing in the industry. Second, improve the development and use of low-carbon sources such as nuclear power and hydropower, and continue to improve the carbon sequestration of ecosystems. Third, government regulation will be tightened, and companies will be brought in to promote regulation and reduce energy consumption while operating. Encourage driving force to improve driving skills and reduce energy consumption by driving the industry and at high speeds[13].

Green supply chain management is a completely new management concept. He wants companies to focus on long-term interests, bring all products as a starting point, and build a network of partnerships, partnerships. share information, and relationships of all members, who want senior leaders to change and improve their strategies. knowledge of the stable development of the industry. Environmental protection is the desired goal of the law in the field of improving human health and economy. Company leaders should actively link business goals, environmental goals, and relationship goals to the chain, so that employees and vendors have access. emphasis on the importance of environmental protection of the industry [14-15]. Figure 11 below depicts the structural model of the low-carbon resilience mechanism.

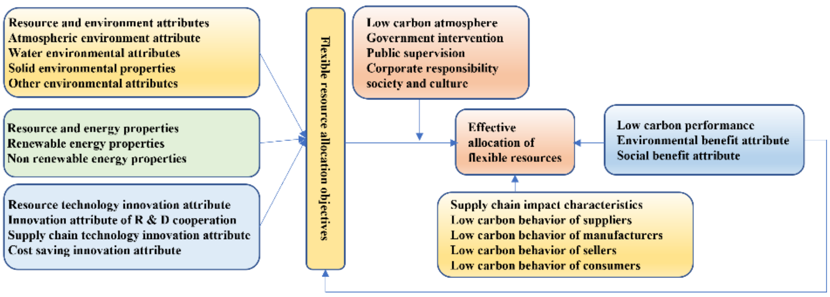



**Figure. 11 An attribute-based structural model of the low-carbon supply chain's flexible resource allocation mechanism**

Enterprises should focus on the green supply chain as a guide to restructure the enterprise operation system, set up green management departments, formulate statistics, monitoring and assessment methods for carbon emission reduction, improve the management system and supervision and implementation mechanism, and provide institutional guarantee for low-carbon production and manufacturing. We should actively adjust the production system, speed up the phasing out of outdated production capacity, processes, technologies and equipment, strengthen energy conservation in production and buildings, carry out green procurement and green services, and actively solve resources and environmental issues that have an impact on enterprises' ability to develop sustainably. While suppliers reside upstream in the supply chain, green supply chain management emphasizes collaboration across every enterprise in the chain [16]. Every supply chain node will get a transmission of their actions, and cost savings can be transmitted to all parts of the supply chain, thereby improving overall efficiency. So leading American companies take suppliers very seriously and choose them very carefully [17]. Table 1 and Table 2 show the test table of the suitability index of a low-carbon supply chain's fundamental resource allocation model:

**Table 1 The suitability index examination of the fundamental resource distribution model in low-carbon supply chain**

| Simulation fit index | Parameter values | The critical value | Structure |
| --- | --- | --- | --- |

| | | | |
|---|---|---|---|
| GFI | 0.913 | >0.9 | Acceptance |
| RMSEA | 0.06 | >0.9 | Acceptance |
| NFI | 0.954 | >0.9 | Acceptance |

**Table 2. Verification table of influence path data of flexible resource allocation in low-carbon supply chain**

| Research on path | Estimation | Standard estimation | CR | SE |
|---|---|---|---|---|
| Renewable energy | 0.113 | 0.148 | 0.031 | 2.874 |
| Non-renewable energy | 0.152 | 0.397 | 0.037 | 3.371 |
| Technology | 0.502 | 0.453 | 0.046 | 6.757 |
| Research and development | 0.101 | 0.117 | 0.028 | 3.361 |

## 4 Design of resource allocation parameters of low-carbon supply chain based on Internet of Things and environmental responsibility

### 4.1 Create a low-carbon supply chain with flexible resource allocation parameters

In order to improve and effectively improve the characteristics of flexible substrate in low-carbon materials, and to enhance resource distribution level and efficiency, this article specially designed the exchange capital of low-carbon products. The parametric design diagram of a hybrid neural network model is shown in Figure 12 below.

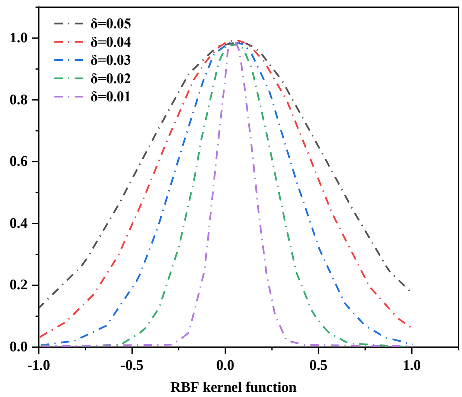



**Figure. 12 Structural parameter design of hybrid neural network based on radial basis function**

Therefore, it is necessary to design the configuration parameters according to flexible resources' characteristics in the low-carbon supply chain, and finally achieve the low-carbon supply chain's overall optimization objective for flexible resource allocation parameters. In the analysis of resource and environmental attribute list of low-carbon supply chain, attention should be paid to the collection of data, the extraction of effective attribute characteristics, and the elimination of redundant characteristic attributes [18]. Then, a complete set of flexible resources and environmental attributes of low-carbon supply chain can be established to analyze the characteristics of flexible resources and environmental attributes of low-carbon supply chain and other relevant information, so as to clarify the consumption of flexible resources in the production chain and how environmental characteristics are affected. Ensure reasonable allocation of flexible resources in low-carbon supply chain to achieve the overall optimization goal of reducing energy consumption and environmental pollution. Therefore, it is difficult to analyze the allocation of flexible resource attributes in low-carbon supply chain. The flexible resource allocation parameter design of low-carbon supply chain is also reflected in the uncertainty of data and the unbalanced performance of neural network structure in the configuration process, which is also related to the robustness analysis of the configuration model and hybrid algorithm below. In the low-carbon supply chain, Tables 3 and 4 below demonstrate the attribute characteristic scale of flexible resource allocation [19].

**Table 3 Influence the flexible resource allocation scale's distinguishing attributes in the low-carbon supply chain**

| Attribute feature name | Code | Characteristic measurement term |
|---|---|---|
| The atmosphere | RS1 | Carbon dioxide emissions |
| The water | RS2 | Waste water discharge |
| Solid state | RS3 | Solid waste disposal rate |

**Table 4 Descriptive statistical analysis of research samples**

| Attribute code | N | Statistical value | Standard error | Quantity of statistics | Quantity of statistics | Quantity of statistics | Quantity of statistics |
|---|---|---|---|---|---|---|---|
| RS1 | 500 | 4.32 | 0.039 | 0.877 | 0.769 | -0.837 | 0.875 |
| RS2 | 500 | 4.21 | 0.038 | 0.843 | 0.711 | -0.339 | 0.757 |
| RS3 | 500 | 3.27 | 0.036 | 1.032 | 1.066 | -1.640 | 0.252 |
| RS4 | 500 | 3.25 | 0.040 | 1.003 | 1.077 | -1.654 | 0.365 |
| RS5 | 500 | 3.35 | 0.039 | 0.976 | 0.952 | -1.843 | 0.415 |

Therefore, the parameters design of flexible resource allocation in low-carbon supply chain should mainly pay attention to the following aspects: in the structure of hybrid quantum neural network, the learning efficiency value should be mainly paid attention to. Therefore, this paper suggests using the adaptive learning rate of the hybrid quantum neural network's structural activation function design, which is based on the radial basis function of the Gaussian function, to enhance the algorithm's convergence performance [20]. The basic structural equation model of resource allocation elements of low-carbon supply chain is shown in Figure 13 below.

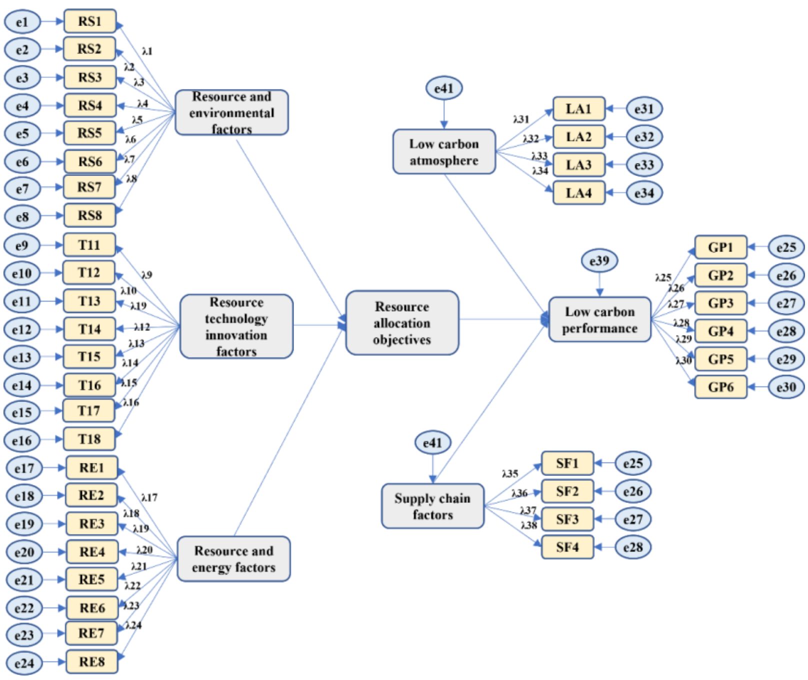



**Figure. 13 Basic structural equation model of resource allocation elements in low-carbon supply chain**

Cloud-based hybrid quantum neural network algorithm must first correct the radial root function and its target error. The maximum weight vector generated by the network is used to process the hidden new neuron of the hybrid neural network structure, so that the iteration finally reaches the maximum number of neurons. Meanwhile, the hybrid quantum particle optimization technique is used in this work to optimize and repair the hybrid neural network and uses the network weight training algorithm to achieve the most efficient results of body weight training. In this letter, in the process of exchanging capital in a low-carbon supply chain, the behavior of flexible resources is divided according to the clustering criterion of the system. intermediate algorithm, minimizing the flexible resource allocation error in a low-carbon supply chain as a result.

### 4.2 Hybrid quantum neural network algorithm for low carbon supply chain

The parameters of the structure hidden layer must be chosen for the hybrid quantum neural network depending on the cloud model, and the activation function of the hybrid network structure should be optimized. The hybrid algorithm can improve the overall performance of the network structure by using quantum particle swarm optimization. If the proper basis function is selected, the approximation ability of the function can be improved, so the convergence speed of the algorithm will be reduced. Therefore, in order to ensure the convergence performance of hybrid network structure learning and effectively improve the generalization ability of algorithm network structure, this essay applies the appropriate hidden layer node number and appropriate basis function of network structure. In this essay, the combination calculation of hidden layer connection weight is designed to improve effectively Network structure stability. In this way, the hybrid quantum particle swarm optimization algorithm can effectively avoid the unstable performance of network structure caused by improper parameter selection, and improve the hybrid quantum neural network structure's control performance efficiently. Figure 14 below displays the structure of the algorithm.

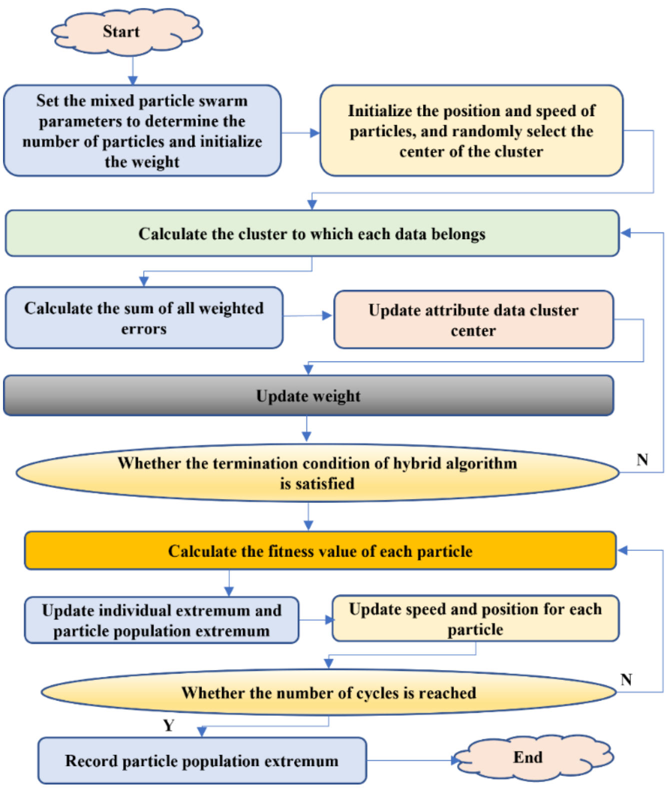


**Figure. 14 Basic algorithm structure diagram**

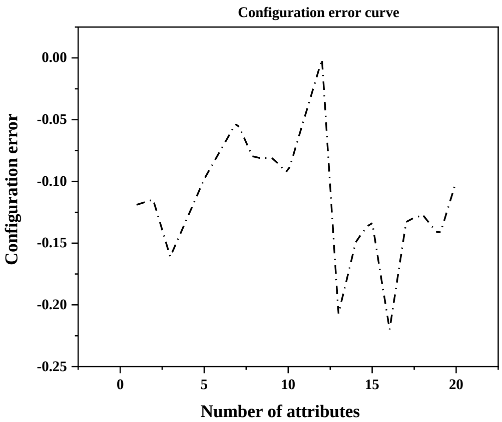
In this essay, when constructing the hybrid quantum neural network structure based on the cloud model, the gaussian function was chosen as the neural network's activation function. The specific activation function design of the hybrid network structure is shown in Formula (5) below:

$$\varphi J\text{（X）}=\exp\text{（}-\frac{X-cj}{2\sigma j}\text{））}，j=1,2，\ldots，J\text{（5）}$$

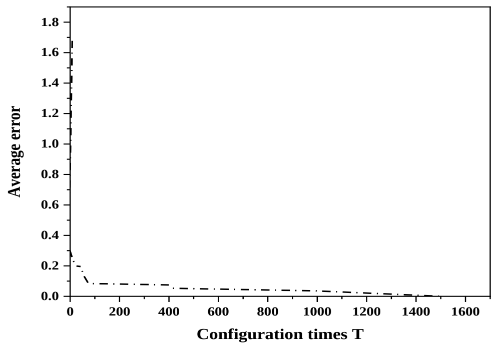
Where φJ（X） is the hybrid network structure's jth radial basis function. An appropriate fitness function is selected by the hybrid quantum neural network method that is based on the cloud model, and formula (6) below illustrates the process used to calculate the fitness function of the hybrid quantum neural network algorithm.

$$F=1/N\text{（}Y_n-Y_J\text{）}^2\text{（6）}$$

Where $Y_n$- shows the hybrid quantum neural network structure's output value following training, $Y_J$ N is the hybrid quantum network structure's sample size and is the hybrid network structure's actual value. As shown in Figure.15 (a) and (b):




(a)




**(b)**

**Figure. 15 Experimental error of flexible resource allocation based on hybrid quantum neural network**

**4.3 Flexible resource allocation solution based on multi-attribute utility association**

Based on the analysis of a low-carbon supply chain's flexible resource allocation model, this essay studies some points that should be paid attention to in the actual allocation process from the perspective of flexible resource attributes of low-carbon supply chain. In this essay, the relevance of resource attribute utility is considered in the configuration process. In the following, the law of resource allocation and the result of allocation are analyzed through the association several low-carbon supply chains' flexible resource features. The resource allocation is analyzed from the perspective of resource attributes, and then the specific analysis is conducted through the experimental results. Figure 16 below depicts the flow chart for the flexible resource allocation model's hybrid quantum neural network algorithm.

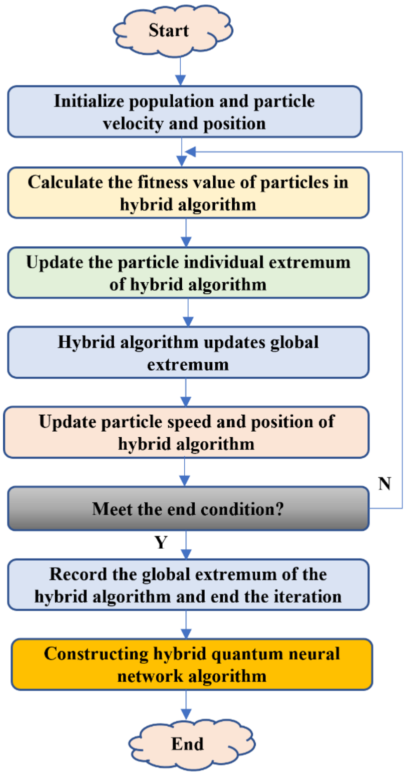



**Figure. 16 Flow chart for the flexible resource allocation model using a hybrid quantum neural network technique**

## 5 Conclusion

To sum up, the current global economic integration and environmental issues have globalized. Facing the increasingly rapid development of globalization, establishing and implementing the low-carbon sustainable development concept is also necessary for nodal enterprises in the supply chain to meet the development goals of the 13th Five-Year Period. We should not only pursue the maximization of the economic benefit of the low-carbon supply chain but also strive to maximize the environmental benefit of the supply chain, to achieve the balance of economic benefit and environmental benefit of enterprises at each node of the supply chain. The research contents of flexible resource allocation in low-carbon supply chains are all hot and difficult areas. The research in this essay mainly focuses on the configuration model and its hybrid neural network algorithm. Although a lot of simulation experiments are applied to carry out relevant verification in the research process, due to the limitation of time and ability, there are still many deficiencies in this research, which need to be further studied and explored.

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**Author Contribution:**

Zhijun Ma: Conceptualization, methodology, investigation, and writing (original draft).
Xiaobei Yang: Methodology, data curation, and validation.
Ruili Miao: Conceptualization, resources, and project administration.
Yiji Yue: Conceptualization, supervision, review, and editing.

All authors contributed equally to the development of the Sustainable development of low-carbon supply chain economy based on the Internet of Things and environmental responsibility.

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