Research on Key and Path of Cold Chain Agricultural Products Supply Chain Transformation Under Double Carbon Target

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Abstract. The realization of low-carbon transformation of cold chain agricultural products supply chain is influenced by multiple influencing factors. This paper uses DEMATEL model to conduct in-depth research and identifies 21 key factors affecting the low-carbon transformation of cold chain agricultural products supply chain. By calculating the influence degree, influence degree, centrality degree and cause degree of each factor, it is further revealed that the cold chain transportation efficiency improvement in cold chain logistics operation, carbon compensation and carbon neutrality plan in energy efficiency and emission reduction, and the rationality of logistics node layout in cold chain logistics network optimization have a significant impact on the low-carbon transformation of cold chain agricultural products supply chain. The above results can provide important theoretical support and decision guidance for the low-carbon transformation of the cold chain agricultural supply chain and the sustainable development of related enterprises.

Keywords: Cold chain agricultural products supply chain; Low-carbon transition; The DEMATEL method

1 Introduction

In the context of global climate change and increasing attention to environmental protection, the government has put forward the "double carbon" goal, that is, "carbon peak, carbon neutrality", aiming to promote the comprehensive green transformation of the economy and society by reducing greenhouse gas emissions. As the foundation of the national economy, the green and low-carbon transformation of the supply chain of agriculture is of great significance to realize the goal of "double carbon". As an important part of the agricultural supply chain, the transformation of the cold chain agricultural product supply chain is related to food safety, resource conservation and environmental protection. This study focuses on the transformation of the cold chain agricultural

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product supply chain under the dual-carbon target, aiming to explore the key elements of the transformation and the realization path. The transformation of cold chain agricultural products supply chain not only involves technological innovation, management optimization and other aspects, but also requires the participation and cooperation of government, enterprises, consumers and other multi-parties.

Domestic and foreign scholars' research on the transformation of cold chain agricultural products supply chain under the dual-carbon goal mainly focuses on the following aspects. First, in terms of the "dual-carbon" policy, Li Sicong and Ye Jing focused on the green development of cold chain transportation under the dual-carbon target, analyzed cold chain transportation, and put forward countermeasures and suggestions to promote structural adjustment and equipment upgrading[1]. Under the guidance of "double carbon" goal, Xiao Yu analyzed the status quo of sustainable development of China's logistics industry, and put forward specific paths at the policy level, management level and technical level, providing a useful reference for the sustainable development of logistics industry[2]. Xi Wenjing and Sun Jin analyzed the green and low-carbon development of logistics enterprises, analyzed the problems faced by logistics enterprises in realizing the "double carbon" goal, and put forward corresponding countermeasures and suggestions [3].

Secondly, the cold chain logistics of agricultural products is studied. Chao and HouPing focus on how to optimize cold chain logistics services for agricultural products in urban areas while ensuring product quality, which is of great significance for improving the efficiency and sustainability of cold chain logistics, especially in the face of complex and changeable distribution needs in urban areas[4]. Mou Jinjin et al. studied the development of cold chain logistics of agricultural products, pointed out the problems such as insufficient application of information technology and insufficient integrated intelligent service, and proposed countermeasures such as integrating logistics information platform and improving the intelligent level of cold chain[5]. In the context of digital countryside, Li Yihua et al. reconstructed the cold chain logistics model of agricultural products and analyzed the improvement effect of the reconstructed supply chain toughness, providing new ideas for the innovative development of agricultural cold chain logistics[6]. Shen Xiaoyu and Zhao Yue conducted a study on the influencing factors of the cold chain logistics chain break risk in the pre-warehouse of fresh e-commerce, established a multi-layer hierarchical network structure model, and dug out the key driving factors [7].

Finally, research methods. In his research, Derse adopted DEMATE method to prioritize the obstacles faced by green reverse logistics, providing a new idea for solving the bottleneck problem in green reverse logistics[8]. Based on the DEMATEL-ISM method, Pang Yan et al. identified the key factors affecting the vulnerability of forest fruit cold chain logistics, and proposed countermeasures and suggestions at the three levels of government departments, industries and enterprises[9]. Wu Di and Jia Shichong established a model of factors affecting the development of cold chain logistics by using DEMATEL method, and revealed the key factors and internal mechanism of the development of cold chain logistics [10]. Anna Wang et al. analyzed the influencing factors of urban logistics system based on DEMATEL method, identified important causes and result factors, and provided useful references for the optimization of urban logistics system[11].

In summary, the existing studies on the transformation of cold chain agricultural products supply chain under the dual-carbon goal mainly focus on the optimization of cold chain logistics distribution network and the reconstruction of agricultural products cold chain logistics mode from the perspective of low-carbon. However, these studies lack a systematic analysis of the key issues facing the transformation of the cold chain agricultural supply chain under the dual-carbon target.II.Materials and Methods.Therefore, this paper comprehensively reviews the practical cases of China's cold chain agricultural product supply chain in green and low-carbon development, and deeply analyzes the main obstacles encountered in its transformation process.The key elements and implementation path of cold chain agricultural products supply chain transformation are proposed, which provides reference for solving the problems of high energy consumption, high cost and high emission intensity of cold chain agricultural products supply chain.

2 Materials and Methods

2.1 Development Status of Cold Chain Agricultural Products Supply Chain

Cold chain supply chain of agricultural products is to ensure the quality and nutritional value of agricultural products in the process of production, storage, transportation and sales. Under the background of agricultural structure adjustment and household consumption upgrading, the scale of production and circulation of agricultural products in our country is expanding. Cold chain logistics of agricultural products is an important part of agricultural products circulation. The scale of China's agricultural product logistics market increased from 3.7 trillion to 5.3 trillion in 2017- 2022, and the scale of agricultural product logistics market increased from 2.7 trillion to 0.48 trillion. This is not only a manifestation of people's increasing demand for fresh and high-quality food, but also an important embodiment of the development of agricultural cold chain logistics.In the development of cold chain agricultural products supply chain, both the government and enterprises have played an important role. The government has issued a series of policies, such as the "Opinions of the Central Committee of the Communist Party of China and The State Council on Learning and using the experience of the" Thousand Villages Demonstration and ten thousand Villages Renovation "project to Effectively Promote the comprehensive revitalization of rural areas", and clearly proposed to optimize the construction of the cold chain logistics system of agricultural products, accelerate the construction of backbone cold chain logistics bases, and layout and construction of public cold chain logistics facilities in county areas. These policies have provided strong support for the development of the cold chain agricultural supply chain. At the same time, enterprises are also actively investing in the construction and operation of cold chain logistics. Some large logistics enterprises, such as SF Express and Jingdong Logistics, have been deeply engaged in the field of cold chain logistics for many years, forming a huge cold chain logistics network with strong transportation, warehousing and distribution capabilities.

2.2 Identification of Influencing Factors

Based on the rooted theory, this paper conducted an in-depth literature search on CNKI, Wanfang Database and other platforms around the keywords "low-carbon logistics", "low-carbon transformation" and "cold chain agricultural product supply chain", combined with in-depth analysis of relevant domestic and foreign literature, strict reference to national (industry) standards, and detailed interpretation of government documents. On this basis, the valuable opinions of industry experts in the field of cold chain logistics industry, agricultural supply chain management and dual carbon, university scholars, and leaders of government departments are widely solicited. The aim is to comprehensively and accurately evaluate the progress and effectiveness of cold chain agricultural products supply chain in low-carbon transformation, so as to further refine the decomposition. After several rounds of discussion and modification, an evaluation index system consisting of four first-level indicators, nine second-level indicators and twenty-one third-level indicators was finally established. For details, see Table 1.

Table 1. Evaluation model of low-carbon transformation of cold chain agricultural products supply chain

Target layer	Primary index	Secondary index	Three-level index	Index literature basis
Evaluation model of low-carbon transformation of cold chain agricultural products supply chain	Energy efficiency and emission reduction C_1	Energy consumption monitoring and management C_{11}	Energy efficiency assessment C_{111}	[9,12,15,16]
			Implementation and effect of energy-saving measures C_{112}	[9-10,14,16]
		Carbon emission control and reduction C_{12}	Carbon Monitoring and reporting C_{121}	[11,12]
			Low carbon technology application effectC_{122}	[17-20]
			Carbon offsetting and Carbon Neutrality Program C_{123}	[10,13,15]
	Cold chain logistics operation C_2	Cold chain logistics network optimization C_{21}	Logistics node layout is reasonableC_{211}	[5,17]
			Transportation route optimization C_{212}	[5-6,11]
		Cold chain transportation efficiency C_{22}	Improved energy efficiency of transport vehicles C_{221}	[6]
			Loss control during transportation C_{222}	[7-9,11,13,20]
			Transit time reduction C_{223}	[11,19]
		Warehousing and inventory	Improved energy efficiency of storage	[16-17,20]

		management C_{23}	facilities C_{231}	
			Inventory turnover optimization C_{232}	[11-13,18]
			Storage environment control C_{233}	[8,11]
	Technological innovation and application C3	Low-carbon technology innovation C_{31}	New energy technology application C_{311}	[9,15]
			Research and development of energy saving and emission reduction technologies C_{312}	[13-15]
		Intelligent and information application C_{32}	Internet of Things technology application C_{321}	[14]
			Big data analysis and optimization C_{322}	[7,12,14]
	Policy and compliance C4	Environmental policy implementation C_{41}	Environmental protection policy implementation measures C_{411}	[7-10,12,15]
			Evaluation of the implementation effect of environmental protection policies C_{412}	[7,12]
		Social responsibility and sustainable development C_{42}	Community environmental protection projects and public welfare activities support C_{421}	[9,15]
			Sustainability report release C_{422}	[5-10,11-12,20]

*1)Energy consumption monitoring and management:*Energy use efficiency assessment is mainly used to measure and evaluate the efficiency of energy use in the cold chain agricultural supply chain, that is, the comparison between the actual amount of energy used and the theoretically achievable optimal energy use[9,12,15,16]. The implementation and effect of energy-saving measures focus on the specific energy-saving measures implemented in the cold chain agricultural products supply chain and their effects. It requires an analysis of the energy saving measures that have been taken [9-10,14,16].

*2)Carbon emission control and reduction:*Carbon Emissions Monitoring and reporting is concerned with the continuous and accurate monitoring of carbon emissions generated in the cold chain agricultural supply chain, and the preparation of carbon emissions reporting in accordance with the specified format and time requirements[11,12].The application effect of low-carbon technology measures the application effect of low-carbon technology in the cold chain agricultural product supply chain, including energy-saving technology and clean energy alternative technology[17-20]. Carbon offset and carbon neutrality plan involves compensating for unavoidable carbon emissions by purchasing carbon sinks and participating in carbon market trading, and formulating and implementing carbon neutrality plans to ensure that the carbon emissions of the supply chain reach the goal of net zero emissions [10,13,15].

*3)Cold chain logistics network optimization:*The rationality of logistics node layout refers to whether the geographical location and scale of each logistics node and the connection between each other are scientific and efficient in the cold chain agricultural products supply chain[5,17]. Transportation path optimization refers to the planning of transportation routes through algorithms and technical means in the process of cold chain agricultural products transportation to find the shortest, fastest or lowest cost path[5-6,11].

*4)Cold chain transportation efficiency:*Energy efficiency improvement of transport vehicles By adopting more energy-efficient and efficient transport vehicles or technologies to transport cold-chain agricultural products, energy consumption and carbon emissions are reduced, and overall transport efficiency is improved[6]. Loss control in the transportation process refers to taking effective measures to reduce the loss of agricultural products in the cold chain transportation process[7-9,11-13,15,20].Shortening transportation time refers to shortening the transportation time of cold chain agricultural products by optimizing transportation routes and improving transportation speed, so as to ensure their freshness and quality, and reduce energy consumption and emissions caused by long-term transportation[11,19].

*5)Warehousing and inventory management:*Energy efficiency improvement of storage facilities: It refers to improving the energy efficiency of storage facilities, reducing energy consumption and carbon emissions, and providing a more environmentally friendly and energy-saving environment for the storage of agricultural products by improving the design of storage facilities and using efficient energy systems[16-17,20]. Inventory turnover optimization: It refers to improving the inventory turnover rate of agricultural products and reducing inventory overhang and waste through reasonable inventory management strategies[11-13,20].Storage environment control: refers to the precise control of the storage environment, such as temperature, humidity, light, etc., to ensure the quality and safety of agricultural products. [8,11].

*6)Low-carbon technology innovation:*he application of new energy technology refers to the use of renewable energy technologies such as solar energy, wind energy and biomass energy to replace traditional fossil energy in the process of low-carbon transformation of the cold chain agricultural supply chain to reduce energy consumption and carbon emissions[11]. The research and development of energy saving and emission reduction technology refers to the energy consumption and emission problems in the cold chain agricultural products supply chain, to carry out relevant technology research and development, in order to improve energy efficiency and reduce unnecessary energy waste and emissions[13-15].

*7)Intelligent and information application:*The application of Internet of Things technology refers to the application of Internet of Things technology in the cold chain agricultural product supply chain to achieve real-time tracking, monitoring and management of items.[14]. Big data analysis and optimization refers to the use of big data technology to collect, analyze and process massive data in the cold chain agricultural product supply chain to find potential optimization points and propose improvement measures[7,12,14].

*8)Environmental policy implementation:*Environmental protection policy implementation measures refer to a series of specific measures taken to ensure the effective implementation of environmental protection policies in the process of low-carbon transformation of the cold chain agricultural products supply chain[7-10,12,15]. The evaluation of the effect of environmental protection policy implementation is to evaluate the actual effect of environmental protection policy implementation measures on a regular or irregular basis[7,12].

*9)Social responsibility and sustainable development :*Community environmental protection projects and public welfare activities support refers to the process of low-carbon transformation of cold chain agricultural products supply chain, enterprises actively participate in and support community environmental protection projects and public welfare activities[7,15]. Sustainability reporting means that companies regularly publish reports on their sustainability status to the public. These reports usually include the performance and progress of enterprises in environmental protection, social responsibility, economic performance and other aspects[5-8,10-12,20].

3 Results & Discussion

According to the evaluation model built in Table 1, we can observe that the influencing factors in the process of cold chain agricultural product supply chain transformation to low-carbon do not exist in isolation, but are intertwined and influence each other. In view of this characteristic, this study decided to use DEMATEL model for further analysis. This method can clearly reveal the structural relationships in complex systems by means of intuitive graphical representation and matrix operation. By calculating the influence degree, influence degree, center degree and cause degree of each factor, we can effectively identify the key constraints. The specific application steps are described below.

3.1 Introduction to the DEMATEL Method

DEMATEL(Decision-making Trial and Evaluation Laboratory) model is a system analysis method based on graph theory and matrix tools, the elements of it by calculating the effect and the effect of, determine the center of the elements and reasons, It reveals the causal relationship between the elements and the position of each element in the system. The analysis steps include the calculation of relation matrix, normative direct influence matrix, comprehensive influence matrix, etc.

3.2 Specific Steps to Apply the DEMATEL Method

*1) The direct influence matrix of each influence factor is constructed:*Through the expert scoring method, experts in the field of logistics are invited to score the influence degree of each evaluation index according to 0, 1, 2, 3 and 4, in which 0 is the lowest influence degree and 4 is the highest influence degree. According to the results of expert scores, the direct impact matrix is obtained. In this paper, a total of 21 three-level indicators are set up, and a direct influence matrix C of 21×21 is constructed.As shown in Table 2.

Table 2. Direct impact matrix

	C_{111}	C_{112}	C_{121}	C_{122}	C_{123}	C_{211}	C_{212}	C_{221}	C_{222}	C_{223}	C_{231}	C_{232}	C_{233}	C_{311}	C_{312}	C_{321}	C_{322}	C_{411}	C_{412}	C_{421}	C_{422}
C_{111}	0	3	1	2	3	1	1	1	1	1	1	1	1	1	2	1	1	1	2	1	2
C_{112}	1	0	1	3	1	1	1	1	3	1	1	1	1	3	3	1	1	2	3	1	2
C_{121}	1	2	0	2	1	1	1	1	1	1	1	1	1	3	1	1	1	1	3	1	1
C_{122}	2	2	3	0	2	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1
C_{123}	1	1	2	2	0	1	1	1	1	1	1	1	1	1	1	1	1	3	4	3	3
C_{211}	1	1	1	1	1	0	3	3	1	1	1	1	1	1	1	1	1	1	1	1	1
C_{212}	1	1	1	1	1	3	0	1	1	1	1	1	1	1	1	3	4	1	1	1	1
C_{221}	3	1	1	1	1	1	1	0	1	1	1	1	1	2	1	1	1	1	1	1	1
C_{222}	2	2	1	1	1	3	3	3	0	1	1	1	2	3	3	1	1	1	1	1	1
C_{223}	1	1	1	1	1	4	4	4	1	0	1	2	1	2	2	2	2	1	1	1	1
C_{231}	1	1	1	1	1	1	1	1	2	2	0	3	1	1	3	1	1	1	1	1	1
C_{232}	1	1	1	1	1	1	1	1	1	2	3	0	2	1	1	1	1	1	1	1	1
C_{233}	1	1	1	1	1	1	1	1	1	1	2	1	0	1	1	1	1	1	1	1	1
C_{311}	1	1	1	2	2	1	1	3	3	1	1	1	1	0	2	1	1	2	3	1	3
C_{312}	2	3	1	2	2	1	1	1	3	1	1	1	1	3	0	3	2	1	3	1	4
C_{321}	1	1	1	1	1	2	2	2	1	1	1	1	1	1	1	0	1	1	1	1	1
C_{322}	1	1	1	1	1	2	2	1	1	2	1	2	1	1	1	4	0	1	1	1	1
C_{411}	1	2	1	1	2	1	1	1	1	1	1	1	1	2	2	1	1	0	4	2	3
C_{412}	1	1	1	1	2	1	1	1	1	1	1	1	1	3	3	1	1	4	0	3	3

C421	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	4	0	2
C422	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	3	3	3	0

*2) Calculate direct influence matrix and comprehensive influence relationship:*The direct influence matrix C is calculated according to formula (1).

$$C = \frac{X}{\max\left[\max\limits_{1\le j\le 21}\sum_{i=1}^{21} x_{ij}, \max\limits_{1\le i\le 21}\sum_{j=1}^{21} x_{ij}\right]} \tag{1}$$

In order to analyze the direct and indirect influence relationships among all factors, the comprehensive influence matrix T is calculated according to formula (2), where T is the identity matrix of 21×21.

$$T = C + C^2 + C^3 + \cdots = \sum_{i=1}^{\infty} C^i = C(I - C)^{-1} \tag{2}$$

According to formula (3)-(6), the influence degree D_i, the influence degree R_j, the centrality degree M_i, and the cause degree H_i among the influence factors are calculated.

$$D_i = \sum_{j=1}^{21} t_{ij} (i = 1, \cdots, 21) \tag{3}$$

$$R_j = \sum_{i=1}^{21} t_{ij} (j = 1, \ldots, 21) \tag{4}$$

$$M_i = D_i + R_j (i = j = 1, \ldots, 21) \tag{5}$$

$$H_i = D_i - R_j (i = j = 1, \ldots, 21) \tag{6}$$

Impact Degree The larger the D_i value, the stronger the influence of the factor on other factors. Impact Rj Indicates the comprehensive impact of a factor by other factors. A larger R_j value indicates that the factor is more strongly affected by other factors. The centrality M_i value indicates the role of an element in the system. The greater the centrality, the more important the element is in the system. The H_i value represents the difference between the influence of a factor on other factors and the affected situation. When the cause degree is greater than 0, it means that the factor is the cause factor in the system and has more influence on other factors.When the cause degree is less than 0, it means that the factor is the result factor in the system. It was more affected by other elements .The calculation indicators of DEMATEL are shown in Table 3.

Table 3. DEMATEL calculates index values

Influencing factor	D_i	R_j	M_j	H_i
C_{111}	3.233704465	2.847279137	6.080983602	0.386425328
C_{112}	3.722840308	3.159892041	6.882732348	0.562948267
C_{121}	3.001095441	2.602761708	5.603857149	0.398333733
C_{122}	2.968452756	3.054974534	6.023427291	-0.086521778
C_{123}	3.509440755	3.110320907	6.619761661	0.399119848
C_{211}	2.681405182	3.0786887	5.760093882	-0.397283518
C_{212}	2.978033709	3.203193447	6.181227156	-0.225159738
C_{221}	2.626327296	3.35932686	5.985654156	-0.732999564
C_{222}	3.718471136	3.095226307	6.813697444	0.623244829
C_{223}	3.727995674	2.572189706	6.300185379	1.155805968
C_{231}	2.998618834	2.565717564	5.564336398	0.432901271
C_{232}	2.705166072	2.663618361	5.368784433	0.041547711
C_{233}	2.386402467	2.485355779	4.871758246	-0.098953311
C_{311}	3.648353409	3.881133831	7.529487239	-0.232780422
C_{312}	4.203020914	3.643077721	7.846098635	0.559943193
C_{321}	2.578169503	3.14307897	5.721248473	-0.564909467
C_{322}	2.987152212	2.829197966	5.816350178	0.157954247
C_{411}	3.462125386	3.657546355	7.119671741	-0.195420969
C_{412}	3.684475982	4.576228821	8.260704803	-0.891752839
C_{421}	2.987840437	3.175676329	6.163516766	-0.187835891
C_{422}	2.875582983	3.980189879	6.855772862	-1.104606897

3.3 Cause Factor, Result Factor and Critical Factor Identification

According to the positive and negative cause degree of each factor, the factors that affect the green low-carbon transformation of the cold chain agricultural product supply chain include: Low carbon technology application effect (C_{122}) : its cause degree is negative, indicating that it is the result of being affected by other factors, rather than the main driving factor. But given that low-carbon technologies are at the heart of achieving a green transition, their promotion and application, despite their inclusion as an outcome factor in this analysis, remains critical. Energy efficiency improvement of transport vehicles (C_{221}) : This factor is also negative, indicating that it is more influenced by other factors. Improving the energy efficiency of transport vehicles is key to reducing carbon emissions, so while it is not the primary driver in this analysis, its improvement is critical to the success of the transition. Environmental policy implementation effect evaluation (C_{412}) : The reason degree is also negative, indicating that the implementation effect of the policy is affected by other factors. However, effective environmental protection policies are an important external driving force to promote the green and low-carbon transformation of the cold chain agricultural supply chain, so their implementation effects need to be continuously paid attention to and improved. Energy Efficiency improvements in storage facilities (C_{231}) : Energy efficiency in storage facilities is an important part of the cold chain agricultural supply chain, helping to reduce energy consumption and carbon emissions. Despite being an outcome factor in this analysis, its improvement has positive implications for the overall transformation. Sustainability Reporting (C_{422}) : Although it is an outcome factor, the publication of sustainability reporting is an important way for companies to demonstrate their environmental commitment and results, helping to enhance their corporate image and drive green transformation. These factors (low-carbon technology application, energy efficiency of transport vehicles, environmental policy implementation effect, energy efficiency of storage facilities, sustainable development report release) are important supporting factors for the green and low-carbon transformation of the cold chain agricultural supply chain.

Through in-depth analysis of the centrality of each factor, we found that the following factors have high centrality values, which reflects that they are particularly closely related to other factors in the whole system, and therefore deserve our special attention: The first is the Low carbon technology application Effect (C_{122}), which, although considered an outcome factor, is strongly correlated to indicate that any improvement in this factor will have a significant positive impact on multiple other related areas, driving overall system optimization. The following is the environmental policy implementation effect assessment (C_{412}). The implementation effect of the policy is not only directly related to the progress of the transformation, but also interacts with many other factors, so we need to continue to pay attention to and improve it to ensure the effectiveness and pertinency of the policy. In terms of energy efficiency and emission reduction, the implementation and effectiveness of energy saving measures (C_{112}) and carbon emissions monitoring and reporting (C_{121}) play a central role. Their improvement will directly contribute to the progress of the overall transition, providing strong support for improving energy efficiency and reducing carbon emissions. Finally, technological innovation is a key driver of transformation. The application of new energy technology (C_{311}) and the research and development of energy saving and emission reduction technology (C_{312}) occupy an important position in the field of technological innovation and application, and their progress will provide a continuous source of power.

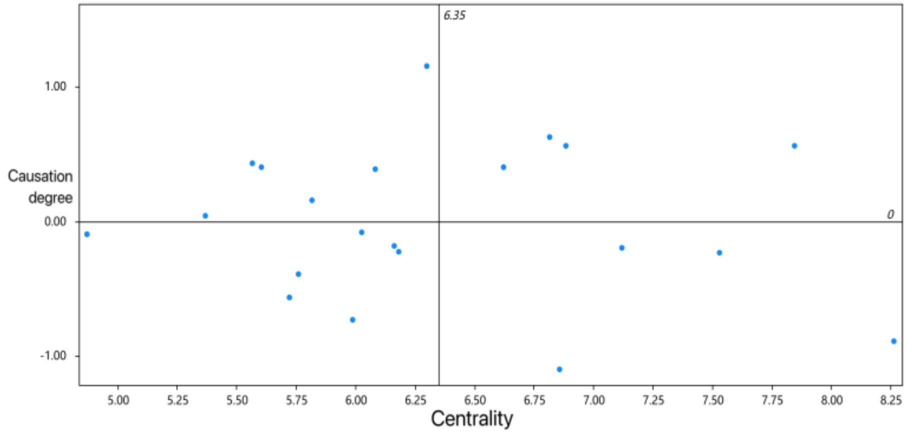

Fig. 1. Centrality of each influence factor - cause degree diagram

As shown in Figure 1,The result factors affecting the green low-carbon transformation of the cold chain agricultural products supply chain in order of absolute value include: Implementation and effect of energy-saving measures (C_{112}) : its high cause degree indicates that it has played a positive role in promoting the transformation, and the implementation and effect evaluation of energy-saving measures is a direct means to reduce energy consumption and carbon emissions. Carbon Emissions Monitoring and Reporting (C_{121}) : Accurate monitoring and reporting of carbon emissions is the basis for assessing transition progress and developing further measures, and is therefore an important outcome factor. Transportation Route Optimization (C_{212}) : Optimizing transportation routes can reduce energy consumption and carbon emissions during transportation, and is the key to improving the efficiency of the cold chain agricultural supply chain. New energy technology application (C_{311}) : The application of new energy technology helps to reduce the dependence on traditional energy and is an important technical means to promote green and low-carbon transformation. Research and development of energy saving and emission reduction technologies (C_{312}) : Research and development of energy saving and emission reduction technologies is a long-term driving force for achieving green and low-carbon transition, and is of great significance for improving overall energy efficiency and reducing carbon emissions.

To sum up, energy efficiency assessment, energy saving and emission reduction technology research and development, carbon emission monitoring and reporting, carbon compensation and carbon neutrality plan, and the rationality of logistics node layout are the five key factors affecting the green low-carbon transformation of cold chain agricultural products supply chain. These factors not only directly promote the progress of transformation, but also interact with many other factors to form a complex transformation system. Therefore, when formulating transformation strategies and measures, it is necessary to comprehensively consider these factors and their interrelationships.

4 Conclusions

Specifically, from the calculation results of DEMATEL, factors such as energy use efficiency assessment, implementation and effect of energy-saving measures, carbon emission monitoring and reporting, carbon compensation and carbon neutrality plan, and rationality of logistics node layout have a high degree of centrality, indicating that these factors play an important role in the low-carbon transformation system of cold chain agricultural products supply chain. At the same time, according to the positive and negative conditions of the cause degree, the cause factors and result factors in the system can be further identified. Among them, energy efficiency assessment, implementation and effect of energy-saving measures, carbon emission monitoring and reporting, carbon compensation and carbon neutrality plan and other factors have positive cause degrees, and are the key factors to promote the low-carbon transformation of cold chain agricultural products supply chain. However, factors such as the rationality of logistics node layout have negative causation degree, which are more affected by other factors and belong to the result factors.

To sum up, the green and low-carbon transformation of the cold chain agricultural product supply chain needs to comprehensively consider a variety of factors, especially those key factors with high centrality and positive causes, in order to promote the realization of the transformation process.

Based on the above analysis conclusions, this paper puts forward the following strategies and suggestions to effectively promote the green and low-carbon transformation process of the cold chain agricultural products supply chain. First, it is necessary to strengthen the efficiency of energy management in the cold chain agricultural supply chain. We should actively promote the application of energy-efficient technologies and equipment, and significantly reduce energy consumption and carbon emissions through technological innovation. This requires enterprises to start from the source, optimize the energy use structure, and ensure that every link can achieve energy saving and consumption reduction. Secondly, the government should play a guiding role and introduce a series of incentive policies. Specifically, enterprises can be encouraged to actively adopt new energy and renewable energy, such as solar energy, wind energy, etc., to provide preferential policies such as tax breaks and capital subsidies to reduce the cost of enterprise transformation. At the same time, the government should also formulate strict energy-saving standards and norms, establish a sound supervision and evaluation mechanism, and ensure that energy-saving measures in the cold chain agricultural products supply chain are effectively implemented. Moreover, it is crucial to encourage companies to invest more in research, development and innovation in energy-efficient technologies. Enterprises should focus on the long term and invest more resources in the research and development and innovation of energy-saving technologies to enhance the implementation effect of energy-saving measures and provide solid technical support for green low-carbon transformation. Finally, the establishment of a sound carbon emissions monitoring and reporting system for the cold chain agricultural product supply chain cannot be ignored. We should strengthen the collection, analysis and disclosure of carbon emissions data to ensure data accuracy and transparency. This not only helps enterprises to deeply understand their own carbon emissions, develop more targeted emission reduction measures, but also accept the extensive supervision of all sectors of society, and jointly promote the green and low-carbon development of the cold chain agricultural product supply chain.

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References

1. Li Sicong, Ye Jing. Double carbon targets under cold chain transport green low carbon development countermeasures [J/OL]. Integrated transport, 1-7 [2024-10-24]. https://doi.org/10.20164/j.cnki.cn11-1197/u.202408 28.001.
2. QU Xiaoyu. Analysis of paths of sustainable development of China's logistics industry under the guidance of "double carbon" goal [J]. ,47 logistics technology, 2024 (15) : 31-33. DOI: 10.13714 / j.carol carroll nki. 1002-3100.2024.15.008.
3. Xi Wenjing, Sun Jin. Analysis on green and low-carbon development countermeasures of logistics enterprises under the goal of "double carbon" [J]. ,47 logistics technology, 2024 (11) : 53-55, DOI: 10.13714 / j.carol carroll nki. 1002-3100.2024.11.013.
4. Chao L ,Ping H .Dynamic modelling of cold chain logistics services under budget constraints for the delivery of fresh products in an urbanarea[J].Applied Mathematical Modelling,2024,125(PA):809-835.
5. MOU Jinjin, Li Jing, Wang Shuyun. Research on the development of agricultural cold chain logistics: Objective requirements, value-added mechanism and development countermeasures [J]. Dongyue plexus, 2024, (7) : 51-58. DOI: 10.15981 / j.carol carroll nki dongyueluncong. 2024.07.006.
6. Li Yihua, Wang Siying, Yang Fang. Cold chain logistics model reconstruction of agricultural products and its impact on supply chain toughness in the context of digital countryside [J/OL]. Central south forestry university of science and technology to learn, 1-8 [2024-10-24]. http://kns.cnki.net/kcms/detail/43.1470.S.20240718.1757.004 HTML.
7. Shen Xiaoyu, Zhao Yue. Fresh electricity lead warehouse cold-chain logistics chain scission risk factors research [J]. Journal of safety and environment engineering, 2023, 30 (01) : 9 to 18. The DOI: 10.13578 / j.carol carroll nki. Issn 1671-1556.20211377.
8. Derse O .Prioritizing solutions of green Reverse logistics barriers with Fuzzy DEMATEL – FUCOM – SWARA The methods [J]. Ecological Indicators, 98-2024165121.
9. Pang Yan, Deng Qiyuan, Wang Zhongwei, et al. Identification of key factors affecting cold chain logistics vulnerability of forest fruits based on DEMATEL-ISM [J]. Central south forestry university of science and technology study, 2024, 44 (03) : 136-148. The DOI: 10.14067 / j.carol carroll nki. 1673-923 - x. 2024.03.014.
10. Wu Di, Jia Shichong. Research on Influencing factors of cold chain logistics development based on DEMATEL-ISM model [J]. Journal of shenyang normal university (social science edition), 2023,47 (6) : 88-93. The DOI: 10.19496 / j.carol carroll nki SSXB. 2023.06.002.
11. Wang Anna, Qian Chengjiang, Wang Xuedong. Analysis of Influencing factors of urban logistics system based on DEMATEL [J]. Material Flow Technology,2022,41(10):58-61.
12. M. A M B, Simoes B S D,Bogo M S, et alSustainable practices in last-mile logistics of small Brazilian e-retailers: an analysis using an MCDM approach[J].Academia Revista Latinoamericana de Administracion,2024,37(3):383-408.
13. Dai Yiran. Study on low-carbon Transformation of logistics economy in Huaihai Economic Zone [J]. ,47 logistics technology, 2024 (17) : 100-103 + 129. DOI: 10.13714 / j.carol carroll nki. 1002-3100.2024.17.025.
14. Cheng Yimin. Identification and Analysis of Key Influencing Factors of Emergency Logistics Supplier Evaluation [J]. Logistics Engineering and Management, 2019,46(06):1-4+8.
15. Shen Danyang, Cheng Yujie. Exploration on key Influencing Factors of urban end delivery demand of UAV logistics [J]. Logistics Technology, 2019,43(05):13-24. (in Chinese)
16. Ahmad S M ,Fei W ,Shoaib M , et alIdentification of Key Drivers for Performance Measurement in Sustainable Humanitarian Relief Logistics: An Integrated Fuzzy Delphi-DEMATEL Approach[J].Sustainability,2024,16(11):

17. Li Na, Guo Chuijiang, Wen Zhili. Analysis of Influencing factors on Efficiency of agricultural cold chain logistics enterprises based on intuitionistic fuzzy DEMATEL Method [J]. Journal of Shandong Jiaotong University, 2019,31(04):75-82.
18. Xu Wenping, Lu Yu. Analysis of Influencing factors of emergency supply chain elasticity based on DEMATEL-AISM [J]. Logistics Technology, 2019,42(06):102-106.
19. CAI Yujia, YUAN Pengwei, WANG Jin. Vulnerability Evaluation of fresh logistics System [J]. Journal of Material Flow Technology, 2002,41(10):46-52+67.
20. Hu Lili, Liu Aiqin. Evaluation of emergency logistics system based on DEMATEL-ANP [J]. Logistics Technology,2022,41(08):36-40.