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Original article

Study on the harmonious development of regional logistics coordination and the geographical environment from a low-carbon perspective

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ABSTRACT

It is clarified that evolutionary conditions are the premise and foundation of the study of evolutionary dynamics, and the study of evolutionary dynamics is the basis for the division of evolutionary stages and their characteristics. Secondly, in the study of evolutionary conditions, it is argued that internal and external environmental conditions, dissipative structural conditions, and rising and falling conditions are the specific evolutionary preconditions of coordination in the perspective of a low carbon economy. The harmonious development of regional coordination and ecological environment is an important guarantee for the sustainable development of the region. This paper provides an in-depth study and analysis of the coordinated development of regional coordination and the geographical environment through a low-carbon perspective. Firstly, the three relationships of evolutionary conditions, evolutionary dynamics, and evolutionary stages are analyzed through the analysis of the applicability of self-organization theory in the study of coordination evolution from the perspective of a low-carbon economy. First, we take the composite system of "coordination and ecological environment" as the research object, and use the theory of cooperation to construct a scientific and systematic index system of orderly parameters of the coordination subsystem and ecological environment subsystem, and establish the model of the orderliness of subsystem and the model of coordination of the composite system. Finally, we analyze the reasonableness of the calculation results based on the development of coordination and ecological environment and propose countermeasures from three aspects: the formulation of regional development policies and regulations, the construction of regional coordination public information platform, and the optimization of the energy structure of the coordination industry.

1. Introduction

With the rise of the global population and the continuous growth of the economic scale, increasing environmental pollution problems appear in front of us. In recent years, carbon dioxide emissions have gradually increased, climate warming, sea-level rise, long-term haze, greenhouse effect, and other problems have emerged, and the development of countries and regions around the world has been negatively affected, and the quality of life of the public can hardly be guaranteed (Cheshmehzangi, 2021). Against this background, countries around the world have started to find a balance between social development and environmental protection, and have begun to advocate a sustainable development model with low emissions, low energy consumption, and low pollution, and a low-carbon economy has come into being. In a theoretical sense, studies on the efficiency of the coordination industry have been mostly analyzed by relevant scholars from the perspective of input and output, pursuing only economic benefits and efficiency, ignoring the problem of environmental pollution brought about by development (Li and Wang, 2022). This study distinguishes itself from other literature by evaluating the efficiency of the coordination industry based on a low-carbon perspective, which is more in line with the theme of today's low-carbon economic development. Meanwhile, based on traditional production theory, correlation analysis, and network hierarchy analysis, the evaluation index system of coordination industry efficiency under a low-carbon perspective is constructed, which enriches the

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research on the evaluation index system of coordination industry efficiency. Finally, two efficiency evaluation methods are combined to evaluate the efficiency of the coordination industry based on dynamic and static perspectives, which broadens the application scope of the two methods. This imbalance fully reflects the lack of development capacity and opportunities in the lagging regions, and even some lagging regions may fall into the cumulative cycle of underdevelopment, which in turn causes the increase of financial risks and social risks in the lagging regions. Underdevelopment in the lagging regions can also inhibit the expansion of market scope in the developed regions, leading to traffic and housing congestion and higher production and living costs in the developed regions due to excessive population concentration, which in turn constrains the development potential of the developed regions. In addition, there are serious imbalances in the rate of economic growth between regions, serious convergence of industrial structures in different regions, irrational allocation of regional resources, serious fragmentation of regional markets, increased friction, or conflict of interests between regions, and so on (Espegren et al., 2021). The existence of the above-mentioned regional problems seriously affects the interactive development of the interregional economy, the full development of the regional economy, and the balanced development of the interregional economy. If regional economic "imbalances" are not improved promptly, they will not only affect equity, but also the overall economic layout and efficiency of the country, the growing needs of the people for a better life, and the core competitiveness and comprehensive national power of the country.

The coordination industry is a basic and strategic industry that supports the development of the national economy and is an important part of the national economy. As a regional commodity processing and manufacturing center and distribution center, the high-quality development of cities requires the construction of a comprehensive social urban coordination service system with complete functions, high operational efficiency, and strong service capacity (van Geet et al., 2021). Taking the regional "logistics-ecological environment" complex system as the research object, and using the theory of synergetic, a scientific and systematic logistics subsystem and ecological environment subsystem order parameter index system was established, and the order degree model of the subsystems and the coordination of the complex system were established. As an important part of urban economic activities, urban coordination and urban economic development are interdependent and promote each other, and are the bridge and foundation of economic exchanges between cities. In the process of linking production, circulation, and consumption, urban coordination serves the flow of production factors and products needed for life within the city area and the circulation activities brought by the exchange of production factors and products between cities, and plays a vital role in realizing the effective allocation of urban resources, enhancing the professional operation level of related industries, and promoting industrial structure adjustment. The promotion of urbanization is the main motive for the development of urban coordination (Jiang et al., 2021). The high-speed urbanization process in China brings a large amount of coordination demand, which becomes important support for the development of the coordination industry, while the development of urban coordination in turn also promotes the process of urbanization, and the service capacity of urban coordination directly affects the radiation capacity of the urban economy. The low carbon economy development model has become an urgent need and universal consensus in the world because of its characteristics of low energy consumption, low emission, and low pollution. At present, from the national level to the provincial and municipal areas, all of them are actively implementing the concept of green development, changing the mode of economic development, and implementing low-carbon development strategies to achieve sustainable development. In this context, regional coordination, as a major energy consumer and carbon emitter, must protect the ecological environment, reduce energy consumption, and take responsibility for carbon emission reduction while developing rapidly.

Therefore, under the perspective of low-carbon development, how to realize the coordinated development of regional coordination and ecological environment has become a real problem that must be faced and needs to be solved, and it is of great theoretical and practical significance to conduct relevant research in this area. In general, the research on the coordinated development of regional coordination has achieved certain results, but due to the different perspectives and depths of scholars' understanding, there are still some shortcomings in the existing research as follows. Most of the research focuses on the coordination between the two subsystems of regional coordination and regional economy, but the ecological and environmental factors that have an important impact on these two systems are not considered in the study. In the construction of the eco-environmental system, many of the selected indicators are not closely related to the regional coordination development and do not consider the resource consumption, energy consumption, carbon emission, and other environmental factors directly generated by coordination activities. Based on this, this paper takes the sustainable development of the coordination industry as the research object, takes the composite system of "coordination and ecological environment" as the research object, builds a scientific and systematic index system of coordination subsystem and ecological environment subsystem under the perspective of low carbon development, establishes the subsystem orderliness model and the composite system coordination model, and then uses the historical data to build the subsystem orderliness model. Based on the theory of synergetic correlation, a scientific and systematic index system of coordination and ecological environment subsystems is constructed from the perspective of low-carbon development, a subsystem orderliness model and a composite system coordination model are established, and a regional empirical study is conducted using historical data to calculate the orderliness of coordination and ecological environment subsystems and the coordination degree of the composite system of "coordination and ecological environment", and to analyze the rationality of the calculation results.

2. Related works

The official authoritative survey data reveal that regional coordination has obvious dynamic industrial characteristics and that its disequilibrium exists and evolves over a certain period. Therefore, both the horizontal comparison of coordination development in different regions within the same time and the change of coordination development in the same region at a different time should be analyzed (Ji and Hoti, 2022). The combination of the comparative static analysis method and dynamic analysis method is used to describe and compare the real situation of regional coordination development level in Jiangsu, to analyze the real state of regional coordination spatial disequilibrium more accurately, to find out the dynamic evolution path of regional coordination spatial disequilibrium, to enhance its explanatory power, and to make this study more relevant (Chen et al., 2021). It also combines data analysis and actual phenomena to summarize three manifestations of regional coordination development disequilibrium posture, and summarize the formation and change evolution trajectory law of Jiangsu regional coordination development disequilibrium. At the same time, there is also the need to put forward the institutional design and countermeasure suggestions to promote the

coordinated development of regional coordination in Jiangsu with the help of empirical analysis results and through theoretical deduction when quantitative analysis is not available (Zhang and Li, 2021). Regional coordination is a different state of coordination operation presented in different regional economic development, regional coordination development cannot be separated from the guidance of regional economic development theory, regional economic development theory is the basis of regional coordination development theory (Stojanović and Puška, 2021). The theory of regional economic development includes the theory of regional balanced development and the theory of regional unbalanced development (Cheshmehzangi, 2021).

This theory sees the path of economic development as an "uneven chain", whereby economic development does not occur everywhere at once but is concentrated at the initial starting point (Luderer et al., 2022). The uneven growth theory advocates concentrating limited funds and choosing first to invest in strategically important industrial sectors, or prioritizing investment projects with low social costs and good external economies. In the case of government investment, priority should be given to the public sector, especially for infrastructure development. The corresponding Polarized Effects and Trickling-down Effects are proposed, in which the Polarized Effects dominate in the primary stage of economic development so that regional differences will gradually widen, but overall, the Trickling-down Effects will gradually reduce regional differences (Huang et al., 2020). According to this theory, each industrial sector or product is in different stages of the life cycle, generally going through four stages: germination, growth, maturity, and aging. The rise and fall of the regional economy depend mainly on the stage in the industrial life cycle of the leading industry in the region (Zhang, 2020).

If the region's leading industry is at the stage of innovation development, the region belongs to the high-gradient region, and vice versa, it is in the low-gradient region; if the innovation activities caused by scientific and technological progress are generated in the high-gradient region, after time, they are gradually transferred from the high-gradient region to the low-gradient region in sequence, thus forming a gradient advance pattern and the industrial structure is renewed (Bhaktikul et al., 2021). Whether from the level of basic theoretical research or the level of research methodology, the study of coordination geography has a relatively profound impact on the study of coordination activities and provides an important foundation and conditions for the construction of the disciplinary system of coordination geography, and coordination geography has given many valuable inspirations for the study of regional coordination development.

3. Analysis of the coordinated development of regional coordination and geography from a low-carbon perspective

3.1. Coordinated design of regional coordination and geography from a low-carbon perspective

Self-organization theory is a theory about the self-organization phenomenon that each subsystem within a system can form a certain structure or function among itself according to some rules without external instructions. The theory mainly studies how the system evolves from a chaotic and disorderly initial state to a stable and orderly final state and the laws (Bai et al., 2022). The relationship between the absorption and dissipation of energy of self-organized systems and the organization of order was studied, and the theory of dissipative structure was created. Subsequently, self-organization has been studied from different perspectives, trying to explain how the system moves from disorder to order autonomously. Eventually, self-organization theories such as dissipative structure theory, mutation theory, and chorology were developed. In this paper, we mainly use dissipative structure theory as well as asymptotic and mutation theory, servo theory of covariant students, and evolutionary path theory. The dissipative structure theory is used to study the precondition analysis of coordination evolution in a low carbon economy perspective, the servo theory of covariance is used to analyze the dynamics of evolution, and the gradual and abrupt change theory and the evolutionary path theory are used to study the stage analysis of coordination evolution in a low carbon economy perspective together with the life cycle theory. A nonlinear open system far from equilibrium is transformed from its original disordered state to a temporally, spatially, or functionally ordered state by continuously exchanging matter and energy with the outside world. This new stable macroscopic orderly structure, formed in the non-linear zone far from equilibrium, is called a "dissipative structure" because it requires a constant exchange of matter or energy with the outside world to maintain it.

$$X = \begin{pmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{pmatrix} \tag{1}$$

Gradual change and abrupt change are two forms of development of things. Gradual change is divided into quantitative gradual change and qualitative gradual change. The former refers to the increase or decrease of quantity, that is, quantitative change; the latter refers to the gradual accumulation of new quality and the gradual decay of old quality, which is also a form of qualitative change. The mutation is another form of qualitative change, a break in the gradual process, a leap from one qualitative state to another without any transitional stage. The evolution of gradual changes is extremely slow, inherited from each other, and regular. They initially differ very little, and only after a long period of accumulation of gradual changes do significant differences occur Considering that the role seen now is like the past, there is no sudden dramatic change. Sudden change, emphasizes the meaning of a break in the process of change or a sudden transition. In nature and human social activities, in addition to gradual and continuous smooth change phenomena, there are also many sudden changes and leaps, such as the breaking of rocks, earthquakes, tsunamis, the division of cells, biological mutations, and other phenomena, all elaborate the characteristics of sudden change, as shown in Fig. 1.

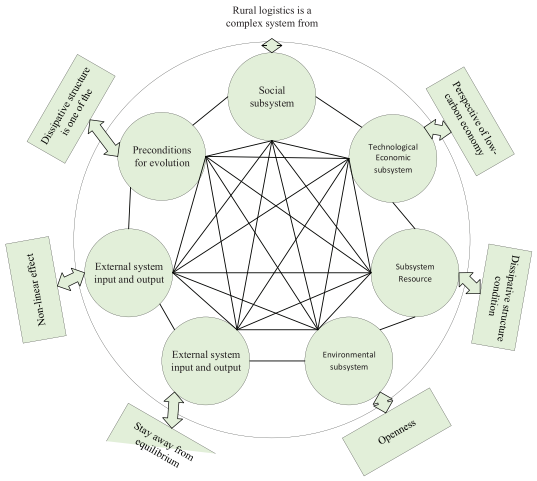

Fig. 1. Dissipative structural conditions.

The study of self-organization theory focuses on the formation and development mechanism of complex self-organized systems, that is, under certain conditions, how the system automatically moves from disorder to order and from low-level order to high-level order. Coordination in the perspective of a low-carbon economy is a large complex system, is in an open environment, from the economy and society, coordination itself a development of low-carbon demand, as well as environmental aspects of a variety of factors to work together in this large complex system, resulting in this large system away from the equilibrium state, showing a non-linear state (Yang et al., 2021). Increased scholars are beginning to study the various economic benefits and environmental issues exposed by coordination. In the early days of coordination, there was no such concept as low-carbon, but with the improvement of living standards and the attention of the government, the existence of coordination in the perspective of a low-carbon economy is a new form, an evolution from a high-carbon state to a low-carbon state.

$$\begin{cases} z_1 = a_{11}x_1 - a_{12}x_2 - \ldots - a_{1m}x_m \\ z_2 = a_{21}x_1 - a_{22}x_2 - \ldots - a_{2m}x_m \\ z_n = a_{n1}x_1 - a_{n2}x_2 - \ldots - a_{nm}x_m \end{cases} \tag{2}$$

$$z_i(k-1) = f(z_1(k), z_2(k), z_3(k), \ldots, z_m(k)) \tag{3}$$

Low carbon economy perspective coordination in the process of production, warehousing, transportation, and processing, there is a phenomenon of low energy efficiency, high energy consumption, and high carbon emissions due to the lack of scientific coordination management, this paper hopes to identify the factors that play a key driving force in the evolution process through the study of Harken model theory, combine these key factors and put forward effective recommendations to improve this high carbon phenomenon and promote the sustainable development of the coordination industry that contribute to the normal production activities of agribusiness and achieve sustainable development of agribusiness in economic development.

$$DF(z^*) = \begin{pmatrix} \gamma_{11} & \kappa_{12} & \ldots & \mu_{1m} \\ 0 & x_{22} & \ldots & 1 \\ \ldots & \ldots & \ldots & \ldots \\ 1 & 0 & \ldots & \kappa_{nm} \end{pmatrix} \tag{4}$$

The regional, decentralized, and complex nature of coordination has led to a higher degree of complexity than urban coordination and is accompanied by environmental problems of low transport efficiency and excessive energy consumption. In the process of rapid economic development, various internal problems of coordination are gradually highlighted, and the energy consumption and carbon emissions of coordination are not controlled, and this waste of resources and high carbon emissions can greatly damage ecological health.

Through the introduction of coordination management methods such as multimodal transport and dumping transport, as well as the replacement of the original high-carbon transport vehicles with new energy technology vehicles, the low efficiency of coordination transport and excessive energy consumption has been largely alleviated. This high-carbon to low-carbon shifts in the development of coordination is the internal conditions for the evolution of coordination from a low-carbon economy perspective, as shown in Fig. 2.

The rise and fall are an unbalanced phenomenon, the actual measurement of coordination in a low-carbon economy perspective at each moment is not exactly on these average values, but deviated, these deviations are the rise and fall of coordination in a low-carbon economy perspective (Qiu et al., 2020). In the early days of the study of coordination-related issues, there was no such concept as low-carbon, and now it must be decarbonized, which is a state of difficulties, into another state, difficulties are the coordination to change the original high-carbon state of existence, into the current state of existence of coordination in the low-carbon economic perspective. The rise and fall of coordination in the perspective of a low-carbon economy is mainly the rise and fall of the economy and society, as well as the development of coordination itself in terms of demand. Inefficient transportation methods are gradually replaced, and multimodal transportation methods and dumping transportation methods are beginning to be used in coordination. With the development of the economy and society, coordination is no longer just a mode of transport serving economic development, the waste of resources and energy consumption in the process of transport also gets attention, a rise, and fall from not focusing on low-carbon development to focusing on low-carbon development. High energy consumption and high-pollution transport vehicles are eliminated, and vehicles with new energy technologies are applied. The use of connected computational coordination systems is a rise and fall from the original state of manual ledgers to the current state of applying computational systems.

$$\frac{\partial V}{\partial z_1} = \frac{dz_1}{dt} \tag{5}$$

The rise and fall of coordination in the perspective of a low carbon economy is a change of the original high carbon state to reach a new low carbon state. Due to the characteristics of regional, scattered, and complex coordination, the complexity of transportation of coordination is high. Using multimodal transportation methods and dumping transportation methods in coordination management, the original transportation method is adjusted to change from the original fragmented transportation state to the scale transportation state. The change from conventional vehicles using gasoline and diesel fuel to new energy vehicles powered by solar energy and electricity is a change from a high energy consumption state to a low energy consumption transportation state. The adjustment of coordination and transportation methods and the application of new energy technologies have caused the phenomenon of the rise and fall of coordination and transportation methods. The original management of coordination is mainly used in the way of the manual ledger in coordination, now are beginning to popularize the network of computer systems, coordination storage system, and coordination transport system in the use of the original high human and high material costs the state to a low human and low material costs of the state. In general, the role of coordination in a low-carbon economy is to change from a high-carbon development state to a low-carbon development state.

3.2. Coordinated development assessment analysis

Some scholars use the level of low-carbon technology input to measure the carbon emissions of enterprises and set the correspondence between the level of low-carbon technology input and the level of carbon emissions, which reflects the inverse relationship between the level of low-carbon technology input and carbon emissions. This assessment method excludes the analysis of details and mainly studies the carbon emissions of enterprises from a macro perspective, which applies to the macro assessment of carbon emissions of enterprises (Daggash and Mac, 2021). The carbon emission limit is a means of limiting the maximum carbon emission amount by a special environmental regulator according to the actual situation of enterprises and the provisions of relevant national policies. The essence of carbon emission allowances is to motivate producers to achieve carbon emission reduction tasks while pursuing their interests, rather than setting clear carbon

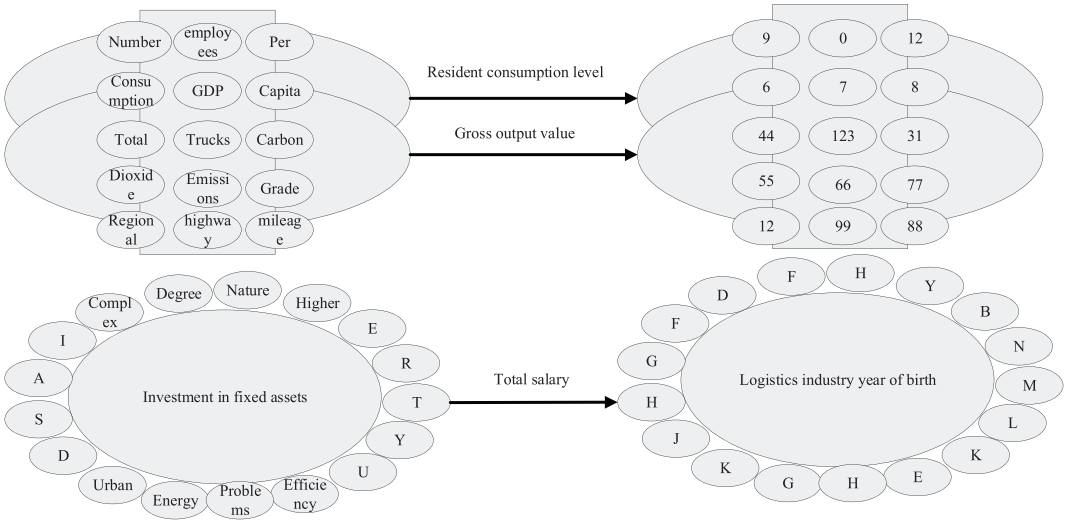

Fig. 2. Correlation chart of evaluation indicators of coordination industry efficiency.

emission reduction tasks or methods for environmental subjects. Since the uneven distribution of carbon emission allowances is the main problem facing carbon emission allowances at present, reasonable distribution becomes a key factor in formulating carbon emission allowance policies.

When a producer emits less than the initial allocation, the producer can sell the remaining credits on the trading market, or, conversely, must purchase additional credits, or face fines and sanctions from the government. In carbon trading, the marginal abatement costs of individual producers are equal, and producers with lower abatement costs get more credit balances by reducing their emissions by the maximum amount and can sell for more returns, while companies with higher abatement costs can buy emission rights to meet the energy-saving and emission reduction regulations without affecting their development. The difficulty in implementing the carbon trading constraint is that it is difficult to accurately assess the carbon emissions of each producer, making it impossible to define the overall carbon emission allowance. If the allowance is set too strictly, it will make it difficult for producers to afford it; if the allowance is set too broadly, it may inhibit producers' incentive to implement emission reduction measures, as shown in Fig. 3.

Carbon trading is a financial activity in which carbon assets are traded and climate change, energy conservation, emission reduction, and sustainable development are considered in an integrated manner under the market mechanism to solve the scientific, technical, and economic problems under the low-carbon development model. The carbon emission trading system is based on the theory of Kes trading, which first sets an allowance for carbon emissions, and then decomposes the allowance into certain units of emission rights and allocates them to individual producers. In a coordination network system, the entire activity of coordination is carried out between nodes via paths. The level and function of the coordination network system depend on the two basic elements of the network, nodes and paths, and their configuration. Both points and lines have a specific spatial distribution, and both interact and eventually form the coordination network structure. Changes in coordination demand and transformation of coordination enterprises will bring about changes in customer requirements, network environment, and constituent elements in the coordination network, and these changes are finally reflected in the proliferation of coordination network nodes and rapid changes in the connection between nodes, which makes the whole coordination network present a dynamic development situation (Huang et al., 2021). Coordination activity is a derivative activity of socio-economic activity. Therefore, the coordination network cannot exist in isolation, and there are a lot of exchanges with the outside world in terms of information, capital, and technology. Through these exchanges, the coordination network can better meet the various needs of society for coordination, and can also continuously improve the service capacity and service level. In addition, a particular coordination network is also bound to interconnect with other coordination networks to expand its service scope. Therefore, the coordination network is a typical open system.

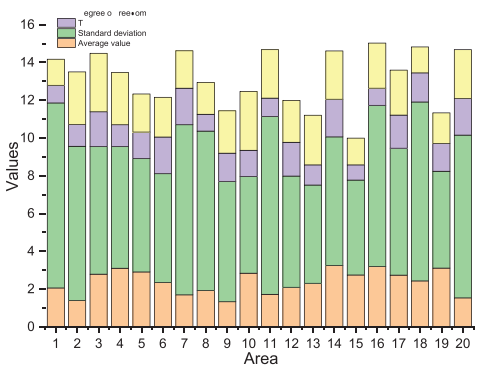

Fig. 3. T-test for paired samples of regional GDP.

Warehousing and transportation are the two most important and basic service functions provided by coordination networks. Warehousing enables the items in the network to span time, solving the contradiction between supply and demand time of coordination network users and creating time value for users; transportation enables the items in the network to span space, solving the contradiction between supply and demand space of coordination network users and creating space value for users. Therefore, the services of coordination networks have a typical Spatio-temporal performance. The nodes and paths of the coordination network, as well as the flow of the items themselves, involve the integration and coordination of various related resources in society. The complexity of these resources and their integration and coordination makes coordination networks complex. Coordination network has a variety of structural forms of existence, and the existence of mutual influence between them.

For example, the coordination network built by each enterprise, the network built between coordination enterprises, coordination enterprises, and other enterprises through mergers, reorganization, alliances, and other ways to form the network. At the same time, the transportation path involved may be a network composed of single or joint transportation. In terms of composition structure, a coordination network consists of coordination nodes and coordination paths, and coordination paths only link the nodes together. Only when with the help of modern information technology and through certain organizational management methods, the items flow on the network according to the needs of users, it becomes a coordination network in the true sense. In other words, a coordination network is a collection of many factors and network structures involving infrastructure equipment, enterprise relationship network, flow distribution network, etc., as shown in Fig. 4.

The economic environment is the economic guarantee for the development of the coordination industry. The economic environment for the development of the coordination industry includes the economic scale and economic structure, with the economic scale being the scale of economic output, which can be measured by the level of economic development, and the economic structure is measured by the industrial structure. The higher the level of economic development, the more countries and regions can provide good economic support for the development of the coordination industry, such as upgrading the level of coordination infrastructure construction, promoting the improvement of human capital in the coordination industry, promoting the research and application of coordination technology, expanding the scope of the coordination market, reducing coordination costs through the scale effect, and improving the efficiency of the coordination industry. The higher the level of economic development, the higher the degree of industrialization and urbanization, the greater the coordination market and coordination demand tend to be, the more sound the coordination infrastructure, the more complete the coordination industry development system, and the higher the quality of coordination industry development tend to be. The higher the level of economic development, the more countries and regions can meet the growing demand for coordination and provide coordination supply that matches the economic and social needs, thus promoting the quality of coordination industry development (Chen et al., 2021). In general, countries and regions with a higher level of economic development and a better economic environment also tend to have a higher quality of coordination development.

The economic structure can be measured by the industrial structure. The optimization and upgrading of industrial structures can provide a good industrial environment for the development of the coordination industry. The coordination industry is a cross-regional, cross-industry and cross-sectoral composite industry, and the optimization and upgrading of industrial structure can drive the optimization and upgrading of the coordination industry through the industrial correlation effect, and then promote the improvement of the development quality of the coordination industry. The optimization and upgrading of the industrial structure can drive the agglomeration of the coordination industry and related industries through the aggregation effect, promote the scale effect of the coordination industry, reduce coordination costs, and improve the development quality of the coordination industry. Through the diffusion effect, the optimization and upgrading of industrial structure can make the coordination industry in different regions produce polarized diffusion and spillover effect, and then drive the development quality of coordination industry in the backward regions to improve.

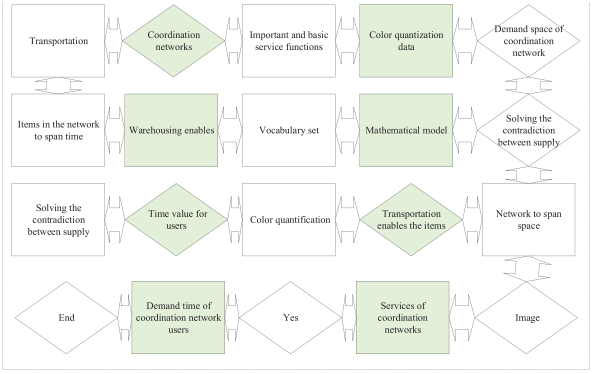

Fig. 4. Coordination network structure.

4. Analysis of results

4.1. Results of coordinated development of regional coordination and geography from a low-carbon perspective

Probability 1 and probability 2 refer to the probability that the regression coefficients calculated by random permutation are not less than and not greater than the actual regression coefficients, respectively. The results of the regression analysis show that the geospatial weight matrix and the urban coordination linkage intensity matrix are positively correlated and pass the 1% significance test, indicating that the closer the distance between cities, the closer the urban coordination spatial association, which is consistent with the first law of geography. The capital stock difference matrix and urban coordination linkage intensity matrix are positively correlated and pass the 10% significance test, which indicates that the similarity of a capital stock helps to enhance the inter-city coordination linkage intensity and is conducive to generating the spatial spillover effect of urban coordination development, as shown in Fig. 5.

Cities with high external linkage intensity and external linkage intensity have a high degree of overlap, mainly in the Yangtze River Delta city cluster, the Pearl River Delta city cluster, and the Central Plains city cluster. In terms of the evolution of the spatial structure, cities with medium or higher external linkage intensity and external linkage intensity in urban coordination are expanding from the eastern region to the central and western regions. The number of cities with high levels of external linkage intensity and external linkage intensity is the largest and thereafter remains at a certain level. The number of cities with high levels of external linkage intensity is more than those with high levels of external linkage intensity in the same period, and the distribution of cities with high levels of external linkage intensity is more dispersed, and

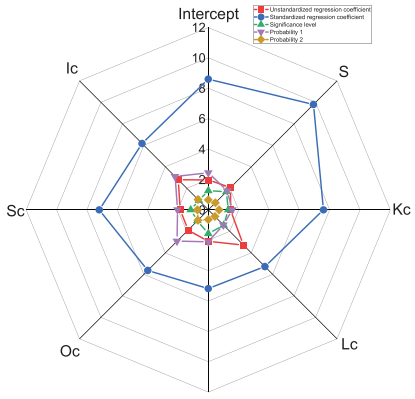

Fig. 5. Results of QAP regression analysis of urban coordination linkage strength and influencing factors.

these cities have completed the initial development of coordination polarization, showing the characteristics of evolution from polarization development to diffusion development.

The division of labor and cooperation among cities within city clusters is more adequate, generating a large amount of inter-city coordination demand and close economic and coordination ties. Among them, the average city coordination linkage intensity of the product requirement document (PRD) city cluster is the largest, indicating that the PRD city cluster has the closest inter-city coordination linkage among the ten city clusters. This result may be due to the slow transformation of the old industrial bases in the northeast region in recent years, the relatively homogeneous industrial structure, the weak economic growth, and the weak inter-city coordination links. The strength of coordination linkages within urban agglomerations in the eastern region is generally higher than that of urban agglomerations in the central and western regions, and urban coordination linkages in urban agglomerations in the eastern region are much closer, as shown in Fig. 6.

The information environment is the information guarantee for the development of the coordination industry. Informatization is the trend of the times, and the information revolution is changing every aspect of economic subjects such as enterprises, governments, and individuals. Network economy theory believes the Internet, as a highly efficient information bank and information exchange carrier, is an important driving force of economic change. For the coordination industry, the popularity of network and information technology can provide timely and accurate coordination information and facilitate the decision-making, docking, and management of coordination participants; Internet of Things, Internet, big data, cloud computing, artificial intelligence, e-commerce, etc. can reduce coordination costs, promote the optimal use of coordination resources, shorten coordination time, and expand coordination market boundaries. The application of intelligent distribution systems, distribution management systems, supply chain management systems, transportation management systems, order processing and tracking systems in the coordination industry, and online customer order placement and tracking systems have greatly contributed to the speed of change and quality change in the coordination industry. This paper uses the Internet penetration rate to measure the information environment, i.e., the number of people with Internet access as a proportion of the resident population is used to measure.

4.2. Results of the coordinated development assessment

The correlation coefficient between environmental regulation and the efficiency of the coordination industry is −1.128, which indicates that environmental regulation is negatively related to the development of the coordination industry. In other words, the current extreme strengthening of environmental regulation will increase the burden of coordination enterprises, which will make them readjust their resource allocation and reduce their coordination resource input, which will affect the development of the coordination industry. However, in the long-term interest, environmental regulation pushes enterprises to use new technologies and innovative management methods, which is conducive to the long-term development of the coordination industry, as well as to reduce carbon dioxide emissions and achieve environmental protection. Therefore, there is a certain necessity to formulate suitable environmental regulation policies at present. The level of infrastructure construction is positively correlated with the efficiency of the coordination industry with a coefficient of 0.782, which is statistically significant. From a macro level, models allow us to better understand the world and how the world works. At the micro level, models can enable us to become clearer and more efficient individual thinkers.

It indicates that infrastructure construction affects the efficiency of the coordination industry, and each unit increase in the level of infrastructure construction will increase the efficiency of the coordination industry by 0.782 units, as shown in Fig. 7.

The level of network informatization construction is positively related to the efficiency of the coordination industry with a coefficient of 0.0683, which is significant at the 5% level. Network informatization construction helps to promote the development of e-commerce, third-party coordination, intelligent coordination, and supply chain platform, which is an important basis for improving the efficiency of the coordination industry. It also indicates that the network informatization construction in Gansu Province has not reached saturation, and it needs to further increase the construction investment, develop network technology, and improve the level of network informatization construction. The correlation coefficient between the level of government management and the efficiency of the coordination industry is −0.0055, which is statistically insignificant. Analyzing the reason, it may be that the calculation formula used is unreasonable, and the ratio of government financial expenditure to regional GDP can only represent the capital investment, not the management level of the government. Talent reserve is negatively correlated with the efficiency of the coordination industry with a coefficient of −0.0016, which is statistically insignificant. It indicates that the talent reserve situation does not have much influence on the coordination industry in Gansu Province, probably because the coordination talent data is difficult to obtain, and it is unreasonable to use the number of

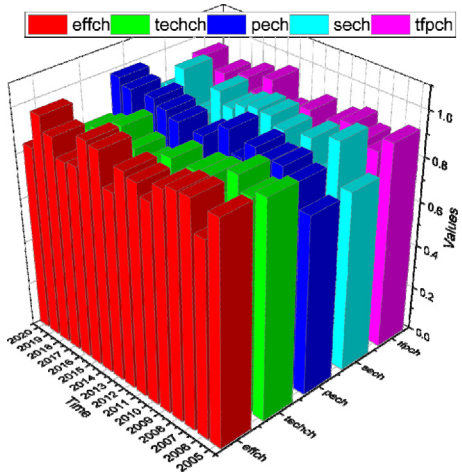

Fig. 6. Dynamic values of the efficiency of the coordination industry.

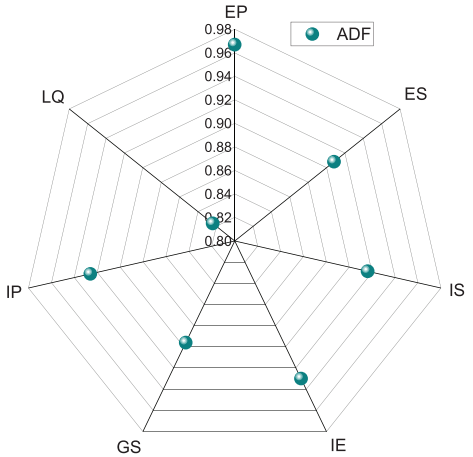

Fig. 7. Time series data stationarity test results.

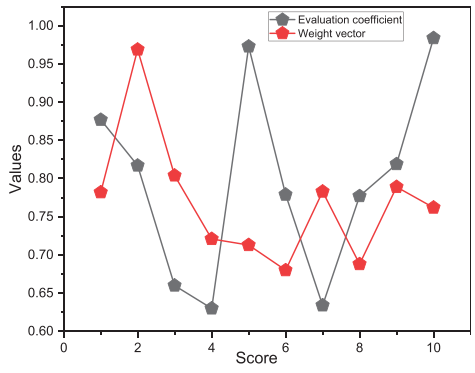

Fig. 8. Grey evaluation number and weight vector of low carbon coordination evaluation indicators.

undergraduate graduates to reflect the coordination talent reserve situation, which leads to deviation of the results, as shown in Fig. 8.

The level of coordination industry agglomeration is positively correlated with the efficiency of the coordination industry in Gansu Province, with a coefficient of 0.632, which is significant at the 5% level. Coordination industry agglomeration is a new development model of modern coordination development, which refers to the integration of coordination enterprises, facilities and equipment, coordination activities, and other elements. Coordination industry agglomeration can promote the formation of scale effect and realize resource sharing, thus reducing coordination cost and improving coordination efficiency. Therefore, the efficiency of the coordination industry can be improved by enhancing the level of agglomeration of the coordination industry. The advantage of our model is that it is faster, more accurate, and more efficient.

Establish an effective inventory management system, increase the utilization area of warehouses, optimize the layout of warehouses; choose electric storage equipment, reduce the energy consumption and carbon emissions of storage equipment; use biodegradable low-carbon packaging materials, reduce disposable packaging; strengthen the recycling of packaging waste, improve the repeated utilization rate of packaging; design simple packaging, reduce the proportion of packaging; change from a decentralized processing model to a centralized processing model. To improve the utilization rate of resources and reduce carbon emissions per unit utilizing large-scale operation; to centralize the problem of edge waste in the process of distribution and processing and reduce environmental pollution. From the whole process of coordination network operation, a low-carbon evaluation index system of coordination network based on four dimensions of coordination facilities and technology, operation management, energy consumption, carbon emission, and resource utilization is constructed, and a multi-level gray evaluation method is used to construct a low-carbon evaluation model of the coordination network, which is solved using MATLAB programming, and a comprehensive evaluation of its coordination network low-carbon is carried out with A coordination company as an example. This empirical study verifies the scientificity and feasibility of the coordination network low-carbon evaluation system on the one hand and proves the accuracy and effectiveness of the multi-level gray evaluation method in coordination network low-carbon evaluation on the other hand.

5. Conclusion

In this paper, we study the problem of designing a low-carbon coordination network under the determination of market demand and carbon emission right price and construct a three-level coordination network design model considering carbon emission to minimize the total cost of coordination network operation. Considering the advantages of the differential evolutionary algorithm in dealing with multi-objective optimization problems, a differential evolutionary algorithm for solving the resource allocation model is constructed, and the method is applied to improve the algorithm to further improve the search quality and efficiency of the algorithm. Finally, the validity of the model is verified by analyzing the coordination network arithmetic of a domestic industrial goods manufacturer. It is found that when the manufacturer receives insufficient carbon emission allowances, the total cost of the coordination network increases with the increase of the carbon emission rights price; conversely, when the manufacturer receives sufficient carbon emission allowances, the total cost of the coordination network decreases with the increase of the carbon emission rights price. In addition, which transportation mode a manufacturer uses in the coordination network depends on the magnitude of the combined transportation costs (including transportation costs per unit of product, carbon emissions costs, and transportation time costs) for each transportation mode. Finally, the frequency of replenishment in a distribution center depends on the trade-off between inventory holding costs and replenishment costs. If the former is too high, the distribution center will increase the replenishment frequency and reduce the inventory holding; if the latter is too high, the distribution center will decrease the replenishment frequency and reduce the number of replenishments. The composite system coordination model used in this paper can objectively and effectively evaluate the level of coordinated development of coordination and ecological environment, and the research method and results can be used for coordination, ecological environment, economics, and other related research. In the study of the coordinated development of regional coordination and ecological environment, this paper mainly conducted a longitudinal comparison and analysis through the historical data of one region but did not conduct a horizontal comparison with other regions, so in future research, relevant data of other regions can be further collected extensively for horizontal comparison, so that the research related to the coordinated development of regional coordination and ecological environment can be more in-depth. In the future, we will optimize and improve the model based on existing research, and strive to make the model more intelligent and convenient.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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