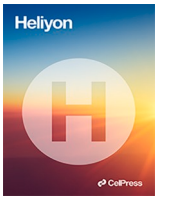
Heliyon 10 (2024) e23884

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon



Coordinated development of China's eco-investing and circular economy coupling based on CRITIC algorithm☆

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ARTICLE INFO

Keywords:
Circular economy
Coupled coordinated development
Green investment
CRITIC algorithm

ABSTRACT

Green Investment (GI) is a financial form of Sustainable Development (SD), which can effectively promote SD. Its development concept, strategy, products and services are in line with the development concept of Circular Economy (CE), which is the development trend of commercial banks and other financial institutions in the future. This paper aimed to promote the efficient use of resources, reduce environmental pollution, improve the health of the ecosystem, provide a better ecological environment for people, and promote sustainable development by integrating ecological investment and circular economy. The development of GI and CE is of great significance for environmental protection, energy conservation and emission reduction, coordination of economy, society, resources, and environment, and it is also a need to promote the development of financial institutions themselves. Based on the research results of GI and CE, this paper analyzed the coupling development of local GI and CE in the eastern, central and western regions by using EM, CRITIC (Criterion Importance Through Intercritical Correlation) method, coupling model, panel data and other methods. It also provided suggestions on the policy of the coupling development of GI and CE in the eastern, central and western regions. This paper started with the relevant economic variables of each year, established the measurement indicators of GI and CE, comprehensively evaluated them using EM, and then studied them using comprehensive evaluation system. The development index of CE in 2020 was 0.3806, but its score in ecological environment was higher than that in 2019. This paper summarized the current development of CE, which can provide experience support and reference for provincial governments in formulating SD strategies and exploring SD paths.

1. Introduction

SD not only refers to its own characteristics of SD, but also means that it has played a role in promoting the SD of human society. On the one hand, the "green capital" created through GI is a long-term capital with lasting vitality and can continuously increase value. The "green productivity" generated by GI is realized through the coordinated development of human, society and nature in the process of transforming nature. Because GI fully considers environmental issues, its investment behavior is different from traditional

☆ Qingwen Ding and Zongbin Zhang reports was provided by Research on the Mechanism and Optimization Path of two-way FDI Synergistic Promotion of Industrial Chain Modernization (21BJL107). If there are other authors, they 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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https://doi.org/10.1016/j.heliyon.2023.e23884
Received 20 February 2023; Received in revised form 13 December 2023; Accepted 14 December 2023
Available online 21 December 2023

investment methods, which has a negative impact on the ecological environment and is beneficial to the SD of human society and future generations. GI can improve the SD of the economy, improve the quality of life of the people, realize the government's macro-control, and enhance the competitiveness of enterprises, the image of enterprises, and the vitality of enterprises. The urgency of environmental issues and the impact of global climate change on the economy, society, and environment, as well as the impact of investment projects on the environment and society, are important motivations for conducting this study. Research methods based on critical algorithms can more accurately assess the environmental risk, social risk and sustainability of investment projects, make up for the shortcomings of traditional investment methods that ignore environmental and social risks, and help promote the practice and promotion of green investment and circular economy. The aim of this study is to explore an evaluation method for the coupling and coordinated development of green investment and circular economy based on critical algorithms, and to provide new investment strategies and methods to promote the practice and development of green investment and circular economy.

Promoting the development and innovation of GI and establishing a complete development model of CE are the inevitable choices for the development and construction of economic circles in different regions. Choi Tsan-Ming believed that topics such as sharing economy and circular Supply Chain (SC) have emerged in production research and operation management in recent years. He briefly analyzed the significance of sharing economy and circular SC in production research [1]. Patrick determined the relevance of CE practice to the achievement of SD goals. He also discussed the synergy that can be produced by CE practice among several goals in the SD goals [2]. Li Qingying considered the design of green products in the SC consisting of one manufacturer and two retailers under the CE. Among them, the goal of retailer 1 is to maximize monetary profit, while the goal of retailer 2 is to be fair. For the former, the cost of GI depends on the green level and production quantity; for the latter, the cost of GI only depends on the green level [3]. Camilleri Mark Anthony believed that EU institutions are increasingly raising awareness of the CE agenda. They encourage market stakeholders to participate in sustainable production and consumption behavior, and successfully plan, organize, implement and measure the CE practice of European sustainable SC, which is both an opportunity and a challenge [4]. Masi Donato believed that CE proposed an economic framework based on the circulation of products and materials. CE is driven by economic factors rather than environmental factors. The deployment of practice is still within the company, not the entire SC [5]. However, their research samples on CE are too few and still need more reference.

This paper aims to use CRITIC algorithm to evaluate the coordinated development of Eco-investing and circular economy in China. This paper intends to use CRITIC method to comprehensively evaluate the relationship between environmental investment and circular economy, so as to realize the synergy between Eco-investing and circular economy, and achieve sustainable development and efficient utilization of resources. The development of this article will help deepen the understanding of the interactive mechanism between ecological investment and circular economy, and provide scientific evaluation tools and decision-making references for decision-makers and relevant stakeholders. This can promote the integration of green development and economic growth, providing theoretical basis and policy recommendations for sustainable development and ecological civilization construction.

With the continuous development of China's economy and society, the construction of ecological civilization has become a strategic position that cannot be ignored by the country. Based on the background of ecological civilization, this paper combines GI and CE, and deeply discusses the development status and existing problems of CE and GI in the central, eastern and western regions. Using macroeconomic data, the index system for measuring CE is selected and constructed, and the EM and CRITIC method are selected for empirical research to ensure the overall effect of the evaluation. Only in a special region, the coupling and coordinated development of two different regions is rarely reported. This paper takes the panel data of the central, eastern and western regions as samples, and uses entropy analysis and coupling evaluation model to conduct empirical analysis on the coordinated development of GI and CE in the ecological civilization environment of each province, thus enriching and developing the connotation of coupling coordinated development. At the same time, the data obtained are also relatively new and have important value for promoting GI and high-quality development of CE. In addition, the ecological level score in 2019 was 0.1240. The evaluation of the coupling and coordinated development of green investment and circular economy based on the critical algorithm adopts the critical algorithm as a specific tool, which can be used to evaluate and diagnose the sustainability of green investment projects and circular economy. It utilizes evidence-based decision support methods to analyze and evaluate the potential risks and opportunities of green investment and circular economy. Critical algorithms can help us coordinate the connection and interaction between green economy and low-carbon economy, as well as the practice and development of green investment and circular economy, promoting sustainable economic and social development. The innovation of this paper lies in providing suggestions for the policy of the coupling development of Eco-investing and circular economy in the eastern, central and western regions, establishing the measurement indicators of Eco-investing and circular economy, and comprehensively evaluating them using entropy method, and studying them using the comprehensive evaluation system to explore the change trend of the investment growth rate and GDP growth rate of environmental pollution control in 2017–2021.

This article adopts various data collection and analysis methods. Firstly, regarding data collection methods, this article collected relevant data on green investment (GI) and circular economy (CE). These data may come from government agencies, financial institutions, environmental protection organizations, etc., to ensure the reliability and accuracy of the data. At the same time, qualitative and quantitative data may be obtained through methods such as face-to-face surveys, questionnaire surveys, and literature research.

Secondly, regarding data analysis methods, this article uses the EM method (Expectation Maximization Algorithm) for comprehensive evaluation, which is used for the comprehensive measurement indicators of GI and CE. EM method is a commonly used statistical learning method that can be used to handle situations with missing data, gradually estimating missing data through iteration, and maximizing likelihood function to achieve parameter estimation.

In addition, this article also uses methods such as critical interval correlation criterion importance, coupled models, and panel data. The critical method can be used to determine the relative importance between indicators and evaluate them based on their importance.

In order to evaluate their coupling development, the coupling model is used to analyze the correlation and interaction between GI and CE. The panel data method can be used to analyze the development and change trends of GI and CE in different regions, and compare their differences and related factors.

Overall, this article uses various data collection and analysis methods to comprehensively and objectively analyze the coupled development of green investment and circular economy in the eastern, central, and western regions, and provide relevant policy recommendations for local governments.

2. Related work

There are a series of urgent problems to be solved in the practice of CE in China. van Leeuwen Kees introduced the establishment of energy and raw material factories in the Netherlands, also known as resource factories. It is regarded as one of the solutions to the global challenge of water resources in the CE [6]. Stefanakis Alexandros I discussed the potential of natural-based solutions in stimulating the growth model of CE, and the key actions needed to improve people's understanding of natural-based methods and attract more investment in the near future [7]. Edwin Cheng T C investigated the links between big data analysis capability, CE practice and sustainable SC. Research showed that CE has no direct impact on sustainable performance [8]. Ghenta Mihaela believed that CE is a concept that has received special attention at present, because it has made contributions to the realization of European goals related to economic development under restrictive environmental conditions. In other words, the implementation of CE activities is essential to maintain and improve the competitiveness of the European economy [9]. Keijer Tom believed that the advocates of CE have cleared the way for the emergence of a new policy framework aimed at redesigning the current economic system. CE is defined as "to maintain the highest value of products and materials through design recovery and regeneration" [10]. Ghisetti Claudia investigated the relevance of CE practices and financing options adopted by small and medium-sized enterprises. When considering the adoption of specific types of CE business model practices and the ability of SMEs to expand their portfolios, his research results were confirmed [11]. Yan Y believed that with the increasing public awareness of environmental protection and extensive upstream investment in green production, some retailers are starting to invest in packaging and distribution processes to shape their public image and enhance competitiveness [12]. Sheldon Roger A believed that the current linear economy of plastic packaging leads to excessive CO_2 emissions and leakage into the environment and needs to be reformed to a greener circular model that both saves resources and benefits the environment. This requires a system-wide redesign of the rules and incentives that apply to the plastics value chain, from product design to recycling and end-of-life options. He identified areas where green chemistry can play a role, and using renewable biological alternatives to replace plastic in fossil resources can reduce greenhouse gas emissions. This can produce plastics that are more easily recycled into original polymers and biodegradable in the environment at the end of their lifespan [13]. Their research on CE has not yet risen to the level of enterprises and countries, and more examples need to be explored.

3. Evaluation methods for the coupling and coordinated development of GI and CE

3.1. Development of CE driven by GI

At present, the protection of environment and ecology and the implementation of green development goals have shown a vigorous development trend around the world. It is the general trend to protect the ecological environment and implement ecological SD. Governments have successively issued a series of laws, regulations, standards and systems, including SD in the national development strategy from the ecological and human perspective. According to the needs of the SD strategy, combined with the basic conditions for the development of CE and the standards for building a socialist harmonious society, to achieve the comprehensive benefits of the environment, economy and society, people must comply with the principles of environmental protection, resource conservation and "triple benefits" to achieve the coordinated development of human and natural environment [14]. These principles are closely linked and complement each other, but they also have their own priorities. First, GI can create green capital that can continuously increase its value. Secondly, the "green productivity" generated by GI refers to the coordinated development of human and nature. In the "GI" model, people combine SD with product production, pay attention to resource conservation, restore natural resources and environment, and achieve ecological balance. Under the guidance of the scientific concept of development, GI is the best investment method for mankind.

(1) Elements of GI for the development of CE

GI is a kind of development investment. Its most prominent feature is that it can produce "green capital" and "green productivity". Green capital is a productive factor with lasting vitality, which can continuously increase its value and provide material support for its development. At present, the lack of funds has indeed brought many obstacles to the development of the CE, such as the pollution of the Yellow River, the treatment of water cut-off, the solution of the power crisis, and the formation and development of green industry, all of which urgently need a large amount of funds [14]. Green productivity is the inevitable requirement for human beings to transform themselves in the process of transforming nature, so as to achieve the harmonious development of human, society and nature. To develop CE, people need to make full use of the power of science and technology to develop and establish a green technology support system. They also need to increase the role of green productivity in the overall economic development through GI [15]. At the same time, it can also bring "win-win" to the economy, society and ecology and promote economic development [16].

(2) The promotion of GI on the development of CE from the perspective of technological relations

From the perspective of technology relations, the promotion of GI on the development of CE can be divided into two aspects: investment governance and investment innovation:

Investment governance is aimed at existing environmental problems. At present, pollution control is the top priority for the development of CE [17]. To do this work well, people should strengthen investment in the environment, and also strengthen the control and elimination of environmental pollution. At the same time, people should take advanced technical measures to avoid all kinds of pollution [18,19]. According to CE, an economic system is an ecosystem with relatively scarce resources and limited environmental capacity. Its resources, environmental capacity and carrying capacity are limited and cannot exceed its ecological critical point. In order to realize the dialectical unity of human survival and natural environment, and establish a harmonious development system between human and nature, people must improve the efficiency of resource use, and organically combine the material cycle and the economic cycle to promote the sound development of the economy.

Investment innovation aims at investment and promotes the formation and development of green industry through GI, so as to realize the harmless and green economy. Green industry is a kind of high-end industry with high knowledge-intensive and suitable for SD. To realize the high-end of traditional industrial structure, people must transform it into green industry [20]. Clean production technology and related systems are the core of the green industrial structure, which is essentially different from traditional clean production. Investment in cleaner production technology can achieve the goal of reduction, resourcefulness and productization, and promote the effect of pollution-free or harmless.

The interaction mechanism between GI and green ecology mainly includes the following aspects: GI can provide a green economic environment and improve social welfare and the resource environment; green ecology can promote GI by expanding financial scale, increasing the proportion of capital allocation, and promoting financial innovation [21,22]. The coupling mechanism of GI and green ecology is shown in Fig. 1.

In Fig. 1, GI (green infrastructure) refers to sustainable urban design that provides ecosystem services through natural and semi artificial natural systems. Green ecology, on the other hand, is a discipline that studies the functions and processes of ecosystems, as well as the phenomena they generate through temporal and spatial interactions. The coupling mechanism between the two mainly includes the following three aspects:

The integration of infrastructure functions and ecosystem services, the construction of GI, and the enhancement of ecosystem sustainability increase public awareness of the ecosystem. In summary, the coupling mechanism between GI and green ecology can provide sustainable urban solutions, improve urban ecosystem service capabilities and ecosystem health, and provide a better living environment for the future of human society and biodiversity.

Evaluation indicators for circular economy:

Resource utilization efficiency: among them, energy utilization rate, water resource utilization rate, and waste recycling rate are important indicators to measure resource utilization efficiency.

Recycling rate measures the impact of waste disposal and reuse, including waste recycling rate, waste reuse rate, etc.

Carbon emission reduction evaluates the carbon emissions and their impact of a company or region in its production process.

Green product production ratio measures the proportion of green products in production, reflecting the level of greening of enterprises or industries.

Ecological restoration ability evaluates the protection and restoration ability of enterprises or regions to the ecological environment.

Economic benefits: people should consider the industrial development and economic benefits under the circular economy model.

Social benefits measures the contribution of circular economy to sustainable social development.

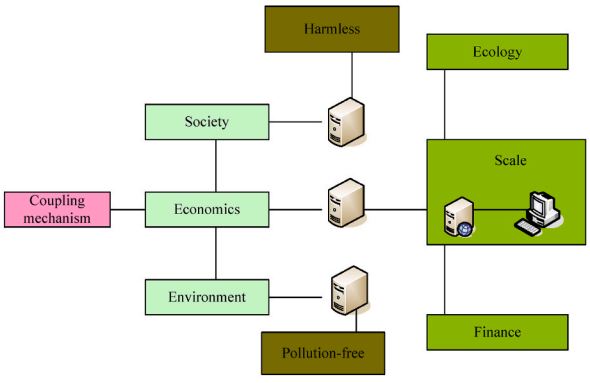

Fig. 1. Coupling mechanism of GI and green ecology

3.2. Measurement of coupled and coordinated development of CE under CRITIC method

In terms of environmental protection and SD, developing GI and developing CE are the themes of the world today. Through the study of GI, CE and the relationship between them, this paper makes an in-depth analysis of the impact of GI and CE development in the eastern, central and western economic regions from multiple dimensions, uses the coupling coordination model to analyze the degree of coordinated development of GI and CE in the eastern, central and western economic regions, and obtains the measurement results. The indicators of these two systems are used to test the degree of interaction among the eastern, central and western regional economies, and some feasible suggestions are given to promote GI in the regional two-city economic circle and promote the development of CE.

(1) Determination of weight

At present, the commonly used methods to determine the weight value include subjective weighting method and objective weighting method. The objective weighting method is based on the relevant methods of mathematical statistics, mainly including principal component method, Entropy Method (EM), CRITIC method, coefficient of variation method, etc.

The EM uses the information EM to calculate the weighted value. CRITIC rules determine the weight of each indicator according to the contrast and correlation between the indicators. On this basis, the EM and CRITIC method are combined to evaluate the high-quality economic development of different cities. In order to obtain the data analyzed in this paper, this paper consulted the official statistical database China Statistical Yearbook, research reports or academic journals to obtain panel data for 30 provinces in China. These sources may include national statistical agencies, government reports, or reputable research institutions that specialize in regional development or economic indicators. This paper uses econometric methods or statistical packages such as R or Stata to perform the necessary data analysis and calculations, including the calculation of high-quality development indices for the eastern, central and western regions.

GI is a means of financing for environmental protection. With the strong support of the government and the guidance of the media, it can improve the public's understanding of green and low-carbon industries, make the whole society incline to green and low-carbon industry ethos, and increase investment in green and low-carbon industries. At the same time, GI would also gather human resources, technology and other resource elements into the resource integration of green and low-carbon industries. Any industry needs funds to achieve long-term development. With sufficient funds, it can create more wealth and continuously invest in green, low-carbon and environment-friendly industries, forming a virtuous circle.

This paper uses the panel data of 30 provinces in China, compares and analyzes the regional differences of the coupling and coordinated development of the east, middle and west, calculates the high quality development index of the east, middle and west economy, and analyzes the high quality development level of the east, middle and west.

Eastern region: Hainan, Tianjin, Shanghai, Jiangsu, Zhejiang, Fujian, Guangdong, Beijing, Hebei, Shandong; Central region: Anhui, Liaoning, Jilin, Heilongjiang, Shanxi, Jiangxi, Henan, Hubei and Hunan; Western regions: Qinghai, Henan, Shaanxi, Guangxi, Guizhou, Sichuan, Chongqing, Yunnan, Xinjiang, Gansu, and Ningxia.

This article uses the CRITIC method to calculate the high-quality development and comprehensive achievements of regional economy. The process is as follows.

Step 1. The amount of information X_j contained in the j-th indicator is:

$$X_j = \beta \sum (1 - r) \tag{1}$$

r is the correlation coefficient.

Step 2. The index weight w_q is calculated:

$$w_q = C_q \Big/ \sum C_j \tag{2}$$

Multiplication synthesis normalization method is adopted for weighted fusion:

$$R_r = R_{1q} R_{2q} \Big/ \sum R_{1q} R_{2q} \tag{3}$$

The high quality development of regional economy and comprehensive achievement Q_j are calculated, and the formula is as follows:

$$Q_j = \sum (G_{Z1} + R_{Z2}) \tag{4}$$

After calculating the high-quality development and comprehensive achievement index of the regional economy, it is also necessary to determine the indicators of circular economy development. When determining the weight of circular economy development indicators, the CRITIC algorithm mainly starts from multiple perspectives, using standard deviation to describe the differences in evaluation results of various schemes under different indicator systems, as well as the degree of contradiction between each scheme under different indicator systems, or the degree of contradiction between different factors. In addition, when there is a significant contradiction between two indicators, the weights assigned to them are relatively high when determining the standard deviation. On

this basis, each indicator can be weighted.

M years and N evaluation indexes are selected, and the corresponding value of the j-th index in the i-th year is Z_{ij}.

All measurement indicators are treated in a unified and standardized manner.

Because the units used to measure each index are different, the numerical actions of the positive and negative indicators are also different (the larger the positive index, the better; the smaller the negative index, the better). In order to avoid affecting the evaluation effect, before calculating the composite index using these two methods, the positive and negative indicators are processed first, and then the standard deviation of the historical data under the j-th indicator is calculated.

The ratio B_{ij} of the index in the i-th year under the j-th index to this index is calculated.

$$B_{ij} = Z_{ij} \Big/ \sum Z_{ij} \tag{5}$$

The correlation coefficient matrix of B_{ij} is calculated.

$$J_Z = \left(B_{ij}\right)_{m\times m} \tag{6}$$

The higher the value of J_Z, the higher the importance of this indicator.

The information quantity l_j of the j-th index is calculated.

$$l_j = \epsilon \sum (1 - J_Z) \tag{7}$$

The weight Q_j of the index of j-th item is calculated.

$$Q_j = J_Z \Big/ \sum J_Z \tag{8}$$

Resource protection: circular economy is a way to effectively use and protect resources to improve the utilization rate and recovery rate of resources, so as to reduce the pressure of the environment on resources and protect limited resources.

Environmental protection: circular economy refers to reducing the consumption of resources, reducing the treatment of raw materials, but also to minimize waste. By improving resource efficiency and recovery rates, environmental pollution caused by mining, energy consumption, and waste disposal can be reduced, thereby reducing negative impacts on the environment and achieving sustainable environmental protection.

Economic benefit: circular economy is of great significance in promoting China's economic transformation and realizing sustainable social development. Improving the utilization rate and recycling rate of resources can reduce the production cost of products, enhance the competitiveness of products, and expand the market share of products. At the same time, the circular economy can also drive the corresponding industrial chain, provide more jobs for the society, and provide more economic growth points for the society.

Energy efficiency: circular economy emphasizes the efficient use and saving of energy to reduce the waste and consumption of energy, so as to achieve the efficient use and recycling of resources. This is of great significance for alleviating the contradiction between energy supply and demand, increasing sustainable supply and realizing sustainable development.

(2) Measurement of CE development

In "Measurement of CE development", "indexes" and "indicators" are two important concepts for studying and evaluating the development of circular economy.

'Indexes' usually refers to a comprehensive index formed by combining multiple relevant indicators. For example, when evaluating a country's level of circular economy development, a comprehensive index can be used to reflect its development in various aspects. This index can cover indicators such as material recycling efficiency, sustainability of product design, and waste management solutions.

Indicators refer to quantitative indicators for evaluating the development of circular economy. For example, indicators applied to measure the development of circular economy can include individual indicators such as waste generation, utilization rate of renewable resources, and waste recycling rate.

Usually, researchers will select appropriate "indicators" based on the determined research purpose and scope to measure different aspects of circular economy development. While using these indicators, it is also necessary to combine them to calculate various "indices" or composite indices to evaluate the overall development of circular economy. This can objectively measure the development of the circular economy and help formulate appropriate policies and guidelines to promote its development.

For the question "Evaluation of the Coupling and Coordinated Development of Green Investment and Circular Economy Based on Critical Algorithms", data collection and analysis usually require the following steps:

Design research methods and sample extraction: in this study, it is generally necessary to design relevant data collection methods, such as questionnaire surveys, interviews, etc., and extract relevant data from samples (investment projects, enterprises).

Data pre-processing: after obtaining data, data pre-processing is required, including missing value and outlier processing, data cleaning, etc.

Model establishment and evaluation: Finally, a model needs to be established to evaluate the data and predict and explain the relationships between relevant factors.

Coupling has always been used in physics, and later has been widely used in other fields and disciplines. It is a manifestation of the interaction of different systems or motion modes. On the basis of coupling, the interaction between various systems is highlighted, thus

realizing the overall development. From the perspective of system theory, coordination refers to the coordinated development and benign interaction between a system or various parts of a system. It is a process of coordinated and orderly development between the whole system and the external environment, as well as between various components, and finally realizes the development of the whole system and its various components. Collaborative scheduling is to measure whether the development between various systems and subsystems is reasonable and reflects the degree of coordination. In short, coordination is a process of transition between subsystems in a system, and coordination is a state of a system, which is a complete, indispensable and inadequate condition of a system. The so-called "coupling and coordinated development" is used to describe the degree of coupling and coordination between systems or subsystems. In this paper, it is proposed to achieve a win-win situation of green finance and CE on the basis of ensuring the ecological bottom line. As a complex and comprehensive system, green finance and CE have the advantages of mutual influence and complementarity, which are of great significance to the development of regional integration.

At present, China's research on the relationship between green finance and CE is still relatively simple, and most of them discuss the role of green finance in the development of CE from both theoretical and empirical aspects. The role of green finance on CE would have a negative impact, so it is not possible to study the relationship between them theoretically. The degree of coupling only reflects the interaction between the two systems, and cannot reflect the coordination between their indicators. There are certain bias and limitations in using only the coupling degree evaluation method. In order to better and more comprehensively and systematically reflect the development degree of China's green finance and CE, and avoid its low development degree, this paper introduces the coupling coordination scheduling model into the coupling coordination measure.

The integration and transmission of information enables investors to grasp the investment value reflected in the GI market. Through information integration and transmission, investors can grasp the effective information of financial products reflected in the GI market. Based on the nature of seeking profit and avoiding harm, investors would choose green environmental protection projects with high return on investment and relatively low risk, rather than taking risks to choose projects with high pollution and high consumption. Compared with traditional projects that are well known to the public, environmental protection projects have higher risks. Even in theory, environmental protection projects are still not the choice of investors. The relationship between green finance and CE is shown in Fig. 2.

In Fig. 2, there is an important relationship between green finance and CE. Green finance refers to the financial activities carried out to support environmental protection and sustainable development. It provides an important source of funds and support for the circular economy. With the continuous development of CE, its position and role in the economy are increasingly valued, thus increasing the demand for green finance. Investors are increasingly paying attention to investment opportunities in the field of circular economy, while the industry is also increasingly inclined to develop and promote environmentally friendly products and services. In this process, the ideas and methods of green finance have been widely used. It not only helps to explore investment opportunities in the field of circular economy, but also creates a better financing environment for small and medium-sized enterprises and start-ups. Therefore, the close relationship between green finance and circular economy is inseparable from the deepening of circular economy and the realization of sustainable development.

The mechanism of Eco-investing (GI) on circular economy (CE):

Financial support and stimulus effect: GI can promote CE construction and promote CE construction. Investors investing in green or CE industries can receive preferential policies such as tax exemptions and subsidies to promote the development of CE.

Technological innovation and demonstration effect: In the development process of CE, the application of GI often requires enterprises to carry out technological innovation and create new production methods. The research results of this project will provide more environmentally friendly and resource saving production models for other enterprises and industries in China.

Market demand and guiding effect: GI can promote the development of environmentally friendly products and also promote the development of CE. Driven by green capital, consumers' awareness of environmental protection continues to increase, and people's emphasis on environmental protection continues to increase. This will inevitably promote the rapid development of CE and promote the transformation of enterprises towards sustainable development.

Resource integration and industrial chain optimization: GI is an important link in the development of CE. It can promote effective

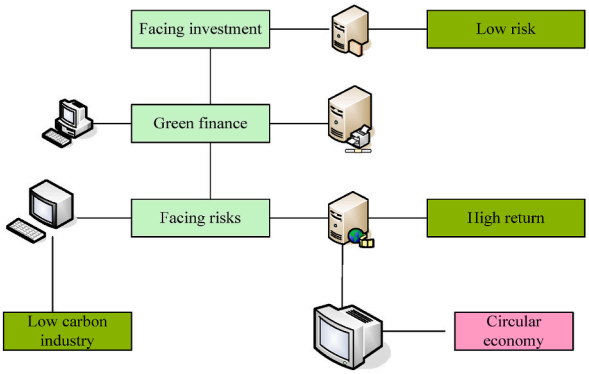

Fig. 2. The relationship between green finance and CE

resource integration and industrial coordination, and is an important link in achieving CE. GI is a new, organized, planned, step-by-step, sustainable industry with significant application value and potential for sustainable development.

4. Results of the coupling and coordinated development of GI and CE

In general, China's total foreign trade has been increasing, from 16654.76 billion yuan to 30641.76 billion yuan in 2021. Under the impact of the global financial crisis, China's GI and trade has decreased in 2020, but also exceeded 18000 billion yuan, surpassing the United States and becoming the world's second largest GI and trade country. In terms of development speed, China's total import and export volume grew relatively slowly from 2017 to 2019. After 2020, China's GI and total import and export volume showed a rapid growth trend. Due to the influence of geography, technology, policy, history, population quality and other factors, the GI and trade in the three main regions of eastern, central and western China also presents regional differences. Therefore, in terms of China's GI and trade, the total exports and imports of the eastern region account for a large proportion. Due to China's infrastructure and geographical environment, China's GI and trade development is relatively lagging behind. In recent years, with the strong support of the Chinese government and the introduction of a large number of foreign capital, the export-oriented economy in the central and western regions has developed rapidly, but the GI and trade between the two countries has not much difference. The changes of GI and trade in various regions are shown in Fig. 3 (the central and western regions are shown in Fig. 3 (a), and the east and the whole country are shown in Fig. 3 (b)).

The degree of openness of a country's economy to the outside world can be measured by its total volume (the breadth of openness) and price (the depth of openness). This paper takes the impact of import and export trade on the urbanization process as the research object, and puts forward a method based on trade dependence.

Trade dependence is not only a measure of the international dependence of a country's economy, but also the openness of a country's economy. Generally speaking, the higher the degree of dependence on foreign trade, the stronger the dependence of national or regional economic development on foreign trade, and the greater the proportion of foreign trade in national or regional economic development. This paper calculates the trade dependence of the whole country and the three major regions of the east, the middle and the west.

From the overall development trend of China's trade dependence, it can be seen that since the reform and opening up, China's trade dependence has shown a fluctuating and continuous upward trend. From the dynamic point of view, China's dependence on foreign trade increased rapidly from 2018 to 2019, reaching a peak of 52 % in 2019. This shows that China's economic growth mainly depends on foreign trade during this period. Since 2019, China's economic growth has shifted from relying on the external pull of foreign trade to the internal pull of adjusting the economic structure and expanding domestic demand. As a result, trade dependence began to decline. The degree of trade dependence among the three major regions of the east, the middle and the west is also very uneven. From the perspective of development trend, the economic development of the eastern region mainly depends on exports, while the dependence of the eastern region on foreign trade is more dependent on imports and exports than the central and western regions. In contrast, western countries are slightly more dependent on trade. According to the difference in the degree of trade dependence on the three major regions, it can be seen that the degree of trade dependence between the east and the central and western regions continued to expand in 2017–2021. In 2020, the trade dependence of the central and western regions is only 8 % and 10 %. The change of trade dependence is shown in Fig. 4 (the central and western regions are shown in Fig. 4 (a), and the east and the whole country are shown in Fig. 4 (b)).

In terms of resource reduction and reuse, the best year was 0.1493 in 2021 and 0.0423 in 2017. In terms of ecological level, the ecological level scores in 2019 and 2021 were 0.1240 and 0.0015. While promoting economic and social development, people must

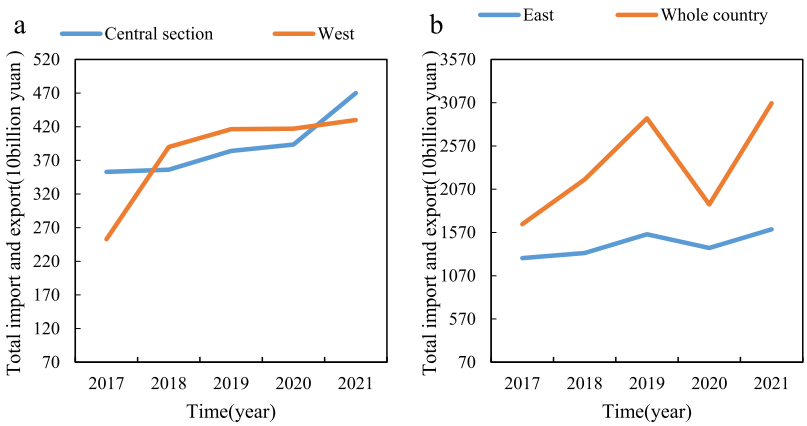

Fig. 3. (a). The total import and export volume of the central and western regions
Fig. 3 (b). The total import and export volume of the East and the whole country
Fig. 3. Changes in GI and trade by region.

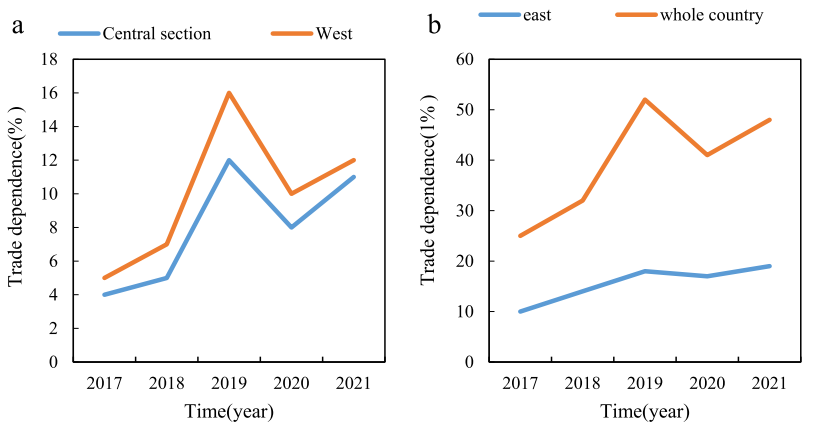

Fig. 4. (a). Trade dependence in the central and western regions
Fig. 4 (b). The trade dependence of the East and the whole country
Fig. 4. Changes in trade dependence.

also pay attention to environmental protection, avoid excessive consumption of resources and energy, and strive to achieve resource recycling. The measured results of entropy in these aspects are shown in Table 1.

According to the analysis principle of EM, the indicators with large utility value include the average annual net income per capita of rural residents, electricity consumption per 10000 yuan of GDP, general industrial solid waste disposal and industrial solid waste production, as shown in Fig. 5 (a). The total amount of chemical oxygen demand emissions, ammonia nitrogen emissions, forest coverage, population density, and internal expenditure of research and development funds is shown in Fig. 5 (b), which makes an important contribution to the application of EM to evaluate the development of CE in each province. This paper used the EM to obtain the corresponding utility value of each indicator, as shown in Fig. 5.

As far as Henan Province was concerned, the development of CE was average. The development level of CE in 2020 and 2021 was very low. The development index of CE in 2020 was 0.3806. However, in terms of ecological environment, the score of CE was 0.1901 higher than that in 2019. Therefore, from this perspective, the development of CE was still good. Therefore, in order to promote the development of CE in Henan Province, people must start with the conservation and reuse of resources and the protection of the ecological environment, combine the green idea with the economic development model, and study the advanced technology and equipment. They also need to improve the production process, and achieve the balance and coordination of the ecological environment. The development of CE in Henan Province is shown in Table 2.

Through the comparison of the three major regions in the east, middle and west, it can be seen that their contribution to GDP was very different. In general, the proportion of GI in GDP in the west was slightly higher than that in the east, but in some years, such as 2019 and 2021, it was slightly lower than that in the east. In central China, the level of GI was significantly lower than that in the east and west. The proportion of total GI in GDP in the three major regions of East, West and Central China is shown in Fig. 6.

The growth rate of investment in environmental pollution control and the change trend of GDP growth rate in 2017–2021 are shown in Fig. 7. The growth rate of investment in environmental pollution control and the change trend of GDP growth curve were basically the same, but in a certain period of time, the peak and the lowest point of the two were not completely consistent. It was often a year or several years later that the GDP growth rate reached a critical point. For example, the investment in environmental pollution control in 2019 was very small, and GDP growth would reach the limit (very low) in 2020. In 2021, the corresponding investment in environmental pollution control would reach the highest point (maximum), while the GDP growth in 2017 would reach the highest point (maximum), which indicated that the investment in environmental pollution control can stimulate economic development to some extent. However, the investment in environmental protection was lagging behind. At the same time, China's investment in environmental pollution control was not entirely consistent with the growth trend of GDP. In some years, its development trend was completely opposite. In 2017–2018, with the increase of investment in environmental pollution control, the growth rate of GDP not only did not increase, but also decreased. The impact of environmental investment on economic development was difficult to determine in the short term. Therefore, the final role of environmental investment on economic development should be viewed from a

Table 1
Entropy measurement results.

Time (year)	Economic system	Resource reduction and reproduction	Ecological environment	Society	Regulations
2017	0.0083	0.0423	0.0105	0.0028	0.0225
2018	0.0562	0.0601	0.1179	0.0195	0.0152
2019	0.0781	0.0821	0.1240	0.0577	0.0923
2020	0.1673	0.1484	0.0751	0.0779	0.1022
2021	0.1903	0.1493	0.0015	0.1657	0.1226

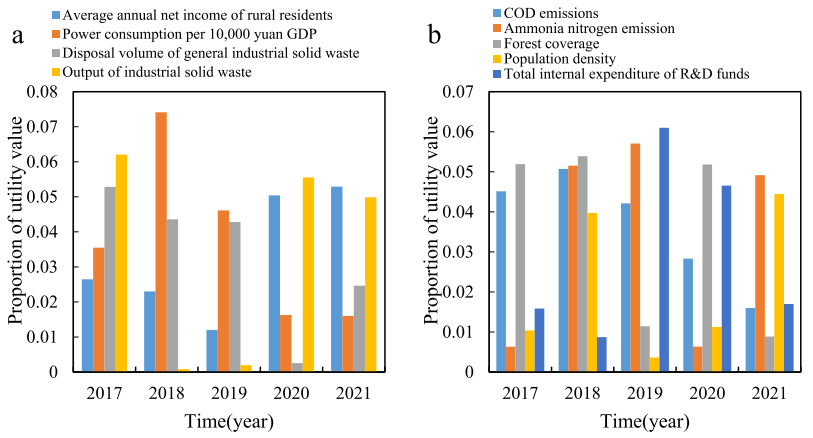

Fig. 5. (a). Rural economy and industrial production
Fig. 5 (b). Environmental and demographic indicators
Fig. 5. Using EM to get the proportion of utility value corresponding to each indicator.

Table 2
Development of CE in Henan province.

Time (year)	Economic system	Resource reduction and reproduction	Ecological environment	Society	Total
2017	0.0072	0.1058	0.2512	0.0761	0.4403
2018	0.1926	0.0872	0.2099	0.0991	0.5888
2019	0.0869	0.1286	0.1772	0.1734	0.5661
2020	0.0072	0.1149	0.1901	0.0684	0.3806
2021	0.0073	0.1208	0.0234	0.1727	0.3242

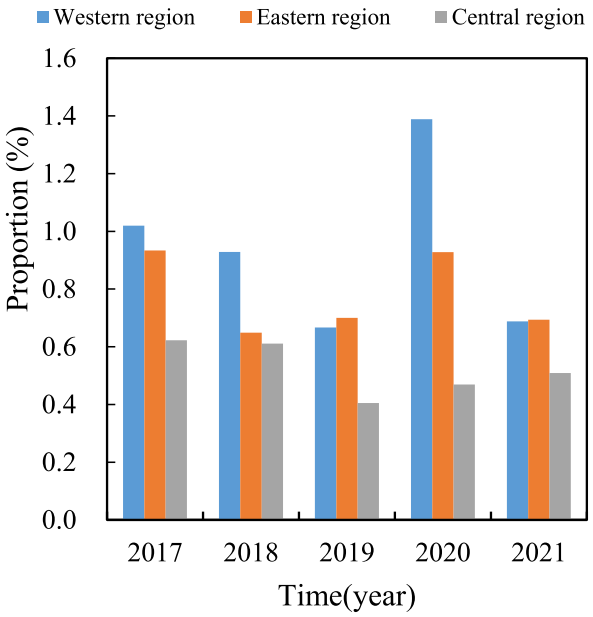

Fig. 6. Proportion of total GI in GDP in the three major regions of the East, the West and the Central.

long-term perspective.

According to the data of China Environment Yearbook, China's GI is mainly concentrated in three aspects: pollution control investment, urban environmental infrastructure investment, and "three simultaneities" environmental investment. Through the comparison of relevant data, it was found that the investment in environmental infrastructure in all provinces and cities in China currently accounted for half or nearly half of the three main fields. However, because the investment in urban environmental infrastructure

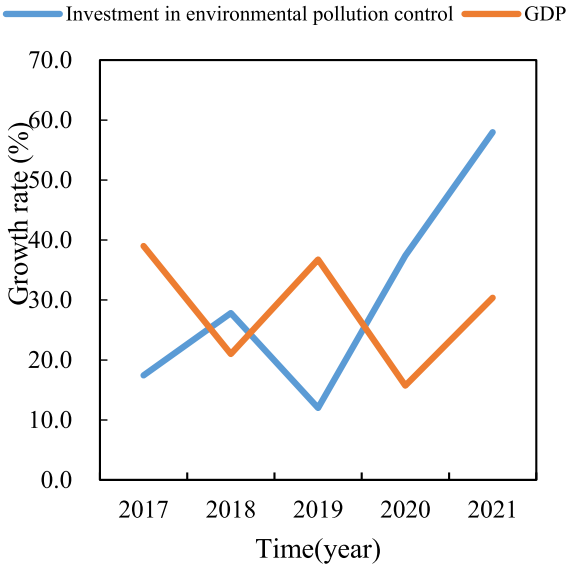

Fig. 7. The growth rate of investment in environmental pollution control and the change trend of GDP growth rate in 2017–2021.

construction (mainly including water supply, heat supply, gas, urban appearance and environmental sanitation and landscaping) and the investment in pollution source control had different demand and supply effects, its impact on economic growth efficiency was different. From 2017 to 2021, the proportion of industrial pollution control investment, “three simultaneities” environmental protection project investment and urban environmental infrastructure construction investment in the three major regions of the east, central and western regions in the total GI from 2017 to 2021 is shown in Fig. 8 (the eastern region is shown in Fig. 8 (a); the central region is shown in Fig. 8 (b); the western region is shown in Fig. 8 (c)). Among the three major components of GI, the investment in urban environmental infrastructure construction accounted for the largest proportion, and most of the investment in various regions and years was more than 50 %.

The regional development of the Eastern Twin Cities Economic Circle had an obvious “dual core siphon” effect, but also had a relatively weak “radiation” effect. This phenomenon has led to the gradual widening of the development gap between the “center” and the “periphery”, which is not conducive to the coupling and coordinated development of “green finance” and “CE”. Therefore, the surrounding small and medium-sized cities should pay attention to the recovery of urban scale. Governments at all levels and relevant departments should fully understand the relationship between green finance and CE, enhance the awareness of green and low-carbon circular development, and compact the responsibility of green development of departments at all levels. They also need to coordinate various resource elements, and increase the scope and work intensity of green finance and CE pilot projects. Combining local advantages, it guides financial institutions and investors to transfer funds to economic activities of green environmental protection, energy conservation and emission reduction. Financial institutions and investors should strengthen financial services for the green environmental protection industry, so that it can better play its guiding role in green finance, thus promoting the high-quality development of green finance and CE. The economic development model, social development degree and cultural development process between different regions are highly similar, which plays an important role in promoting regional cooperation. To solve the unbalanced “fault” development between regions, people can reduce the “siphon” effect of central cities, thus enhancing the radiation and overflow effect, and realize the common development between regions by taking the big cities as the center, so as to improve the coupling and coordinated development of green finance and CE as a whole.

In today’s world, the contradiction between economic development and the environment is becoming increasingly acute. The depletion of natural resources and the deterioration of the ecological environment have seriously restricted the economic development of all countries in the world. At the same time, the issue of GI is also the focus of research in various countries. Developing green CE and realizing GI are the inevitable choice for countries to cope with economic pressure and implement SD strategies. Ecological environment is an important way to realize the idea of ecological civilization. China’s green ecological development has obvious self-reinforcing characteristics and strong inertia dependence. Therefore, the Chinese government should first further improve the overall planning and coordination mechanism for the construction of ecological civilization, analyze it, and summarize successful cases, so as to provide a new way for China’s green ecological SD. People should strengthen policy support, improve relevant environmental protection laws and regulations, establish environmental protection supervision mechanism, and improve the reward and punishment mechanism.

The government should give full play to the role of “strategic guidance”, combine “central” and “western” development, promote the coordinated development of “GI” and “green ecology” through policy guidance, and finally form a "virtuous circle” throughout the country. Secondly, people should increase infrastructure construction, improve living conditions, and strengthen ecological

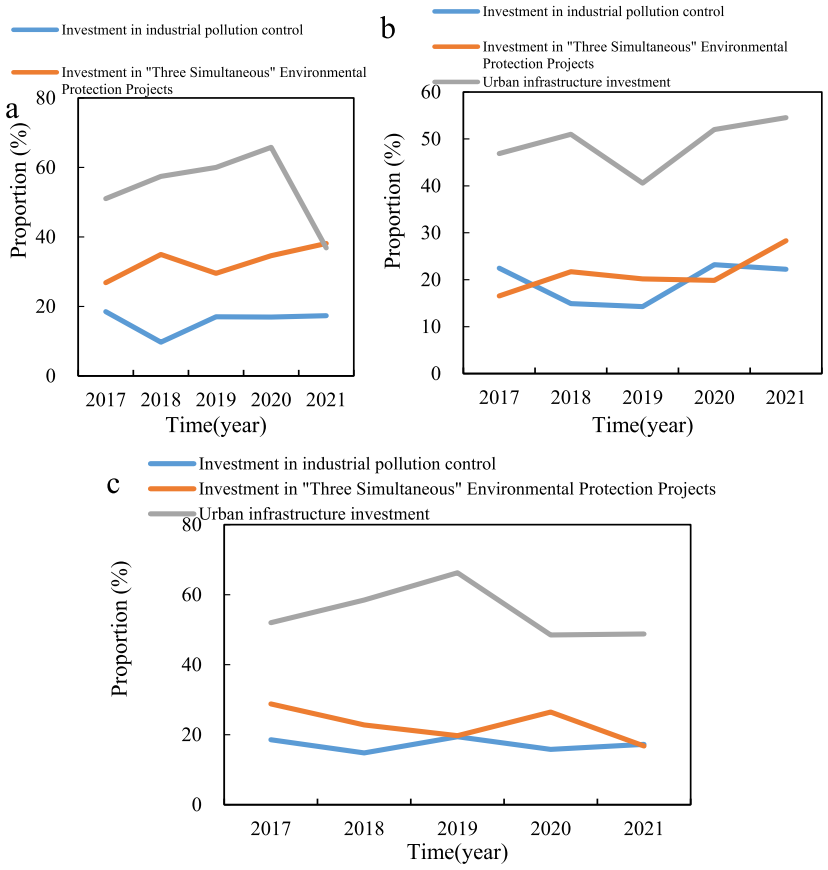

Fig. 8. (a). Investment proportion in the eastern region
Fig. 8 (b). The proportion of investment in the central region
Fig. 8 (c). The proportion of investment in the western region
Fig. 8. The proportion of industrial pollution control investment, "three simultaneities" environmental protection project investment and urban environmental infrastructure construction investment in the three major regions of the east, central and western regions in the total GI from 2017 to 2021.

civilization construction. They also need to highlight green ecological benefits, guide financial and credit funds to flow to green industries, advantageous industries and strategic emerging industries, improve resource utilization efficiency and reduce pollution emissions. Finally, the government would also encourage green energy companies to participate in urban and rural construction to coordinate the government's investment in green ecological construction. For example, small and micro green environmental protection companies are encouraged to participate in the garbage treatment between urban and rural areas, and certain preferential treatment would be given in this year's tax, so as to guide the social funds to the green ecological construction.

Firstly, by comparing the results of this study with relevant literature, it can be found that the study provides a new method and strategy for the coordinated development of green investment and circular economy through the use of critical algorithms. The critical algorithm of this study includes the assessment of environmental risk, social risk and sustainability of investment projects to make up for the shortcomings of traditional investment methods that ignore environmental and social risks.

Secondly, the impact of the research findings on relevant policies and scientific methods should include the following aspects:

It can assist decision-makers in formulating more scientific and reasonable environmental policies, promoting the practice of green investment and circular economy; It can provide important reference and guidance for investors, promote long-term sustainable investment and enterprise development; It can provide new ideas and methods based on key algorithms, providing reference and reference for the research and solution of similar problems.

Finally, it is worth noting that this study may have certain limitations, such as studying only a certain range of investment projects and fund sizes, and in practical applications, more factors and impacts may need to be considered. In addition, the criticism algorithm adopted by the research institute may have certain flaws that require further refinement and improvement.

5. Conclusions

Through the analysis of the development of urban CE, this paper put forward a set of scientific, objective and complete evaluation

methods. From the dynamic point of view, China's dependence on foreign trade increased rapidly from 2018 to 2019, reaching a peak of 52 % in 2019. At the same time, this paper also combined the macroeconomic data of the eastern, central and western regions to conduct a static empirical study of the overall CE in each region. At the same time, according to the monitoring results over the years, the corresponding early warning value was obtained for the early warning signal of the development of CE, so as to predict the operation of CE in each year and dynamically analyze the development trend of CE in each place. The measurement of CE should not only have certain theoretical support, but also be applied to practice. Otherwise, it would lose its due value. With the development of society, the research on the measurement of CE would also change. The research on CE would also be further deepened, and the development of CE would also vary according to the specific situation of the region. The coupling and coordination of ecological investment funds means that financial support is crucial for the development of circular economy. There is a correlation between the formulation of environmental policies and green innovation in enterprises, and policy support may encourage enterprises to invest in green innovation. In order to promote the development of circular economy, people can start by protecting the ecological environment and combining green concepts with economic development models to achieve balance and coordination of the ecological environment. The government can formulate more targeted ecological investment policies to promote the development of China's circular economy. However, this article lacks analysis of different specific scenarios in China, and requires analysis of ecological investment and circular economy based on different ecological environments in China. The interactive relationship involved in this paper is based on GI and green ecosystem, but it has not been specific to the interaction between various systems. These problems need further research and improvement in order to better promote the combination of GI and green ecology. The existing relevant research is mostly theoretical exploration, lacking analysis of specific cases and empirical data. Ecological investment and circular economy involve multiple factors and stakeholders, and the complexity and uncertainty of their interactions may increase research difficulties. On this basis, the practice and effect of Eco-investing and circular economy will be studied to provide support and guidance for the formulation and implementation of relevant policies.

Funding

This work was supported by the National Social Science Foundation project "Research on the Mechanism and Optimization Path of two-way FDI Synergistic Promotion of Industrial Chain Modernization" (21BJL107).

CRediT authorship contribution statement

Qingwen Ding: Writing – original draft. **Zongbin Zhang:** Formal analysis.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests.

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